AD-A257 820

EVALUATION OF EMP/EMI REQUIREMENTS VERSUS CORROSION PREVENTION METHODS

GTRI PROJECT NO. A-8245

U.S. AIR FORCE CONTRACT NO. F09603-88-R-2808

Prepared For

Robins Air Force Base
Warner Robins Air Logistics Center
WR-ALC/CNC
Georgia 31098-5320

Technical Monitor: Mr. David Ellicks
Telephone: (912) 926-3284
DSN: 468-3284
Fax: (912) 926-6619

Prepared by

Dr. Jan W. Gooch,
Mr. Paul M. Hawley
Materials Science & Technology Laboratory
Telephone: (404) 894-8485
Fax: (404) 894-6199

Mr. John K. Daher
Mr. Daniel M. LaGesse
Electromagnetic Environmental Effects Laboratory
Telephone: (404) 894-8228

Georgia Tech Research Institute
Georgia Institute of Technology
Atlanta, Georgia 30332

January 23, 1992

7 Oct 92 Final Report

Evaluation of EMP/EMI Requirements Versus Corrosion Prevention Methods

USAF Contract No. F09603-88-R-2808

Dr Jan W. Gooch
Mr John K. Daher
Mr Paul M. Hawley
Mr Daniel M. LaGesse

Georgia Tech Research Institute
Georgia Institue of Technology
Atlanta Georgia 30332

GTRI Project No. A-8245

Air Force Corrosion Program Office
WR-ALC/CNC
215 Page Rd, Suite 232
Robins AFB GA 31098-1662

N/A

Continuation of GTRI Final Technical Report Contract No. F09603-85-R-0959, 31 Aug 87

Distribution Statement A. Approved for public release; distribution is unlimited.

Final report covers the application of conductive sealants on an E-3 aircraft for nine months and evaluating the Electromagnetic Pulse (EMP)/Electromagnetic Interference (EMI) Requirements and corrosion damage. Also, additional testing was performed on three conductive sealants for corrosion protection via the salt fog chambers. Using conductive sealants will meet both EMP/EMI and corrosion requirements.

EMP/EMI Electromagnetic Pulse Corrosion Protection Electromagnetic Interference Conductive Sealants

297

Unclassified U U UL

EVALUATION OF EMP/EMI REQUIREMENTS VERSUS CORROSION PREVENTION METHODS

GTRI PROJECT NO. A-8245

U.S. AIR FORCE CONTRACT NO. F09603-88-R-2808

Prepared For

Robins Air Force Base
Warner Robins Air Logistics Center
WR-ALC/CNC
Georgia 31098-5320

Technical Monitor: Mr. David Ellicks
Telephone: (912) 926-3284
DSN: 468-3284
Fax: (912) 926-6619

Prepared by

Dr. Jan W. Gooch,
Mr. Paul M. Hawley
Materials Science & Technology Laboratory
Telephone: (404) 894-8485
Fax: (404) 894-6199

Mr. John K. Daher
Mr. Daniel M. LaGesse
Electromagnetic Environmental Effects Laboratory
Telephone: (404) 894-8228

Georgia Tech Research Institute
Georgia Institute of Technology
Atlanta, Georgia 30332

January 23, 1992

A-1

Table of Contents

		Page
1.0	INTRODUCTION	1
2.0	OBJECTIVES	1
2.1	Corrosion Prevention Materials and EMP/EMI Requirements	1
2.2	Corrosion Prevention Materials and Nuclear Hardening	2
2.3	Field Testing	2
2.4	Specification for Use of Conductive Sealants	2
2.5	Qualified Products List for Conductive Materials	2
3.0	RESEARCH PLAN	2
4.0	RESULTS AND DISCUSSION	12
4.1	Evaluation of Laboratory Sealant Test Samples	12
4.1.1	DC Resistance Measurements	13
4.1.2	Shielding Effectiveness Measurements	13
4.1.3	Transfer Impedance Measurements	15
4.1.4	Relationship of Transfer Impedance to Shielding Effectiveness	16
4.1.5	Laboratory Test Results	18
4.2	Field Test Measurements	20
4.2.1	Location of Test Sites	20
4.2.2	E-3A Field Test Results	21
5.0	CONCLUSIONS	22
6.0	RECOMMENDATIONS	23
7.0	REFERENCES	24

List of Appendicies

Appendix A - Shielding Effectiveness Data

Appendix B - Transfer Impedance Data

Appendix C - Drawings for Transfer Impedance Fixture

Appendix D - E-3A Tail Panel Transfer Impedance Data

Appendix E - Specification for Conductive Sealants

Appendix F - Qualified Products List for Conductive Sealants

Appendix G - Sealant Manufacturer's Product Information

List of Tables

Table 1. Test Joints and Identification.

Table 2. D. C. Resistance (Milliohm) Measurements of Test Samples.

Table 3. Average Shielding Effectiveness (dB) of Test Samples.

Table 4. Transfer Impedance (dB-Ohm) of Test Samples.

Table 5. Location of Test Areas on E-3 Aircraft and Conductive Sealants.

Table 6. Corrosion Areas on E-3 Aircraft and Results of Inspections.

Table 7. Results of D. C. Resistance and Transfer Impedance Measurements on E-3 Aircraft.

List of Figures

Figure 1- Profile of E-3 Aircraft.

Figure 2- Top View of E-3A Aircraft.

Figure 3- Tail section and patch (panel), Vertical fin.

Figure 4- Patch (panel) dimensions.

Figure 5- E-3A aft (and forward) entry door.

Figure 6- Block diagram of the shielding effectiveness test setup

Figure 7- Block diagram of the transfer impedance test setup

Figure 8- Front left view of E-3A aircraft showing forward and aft entry doors.

Figure 9- View of the bottom section of the forward entry door and corrosion areas.

Figure 10- View of forward door, bottom view of sealing gasket and corrosion areas.

Figure 11- View of open aft entry door.

Figure 12- View of bottom section of the aft entry door and corrosion areas.

Figure 13- Installation of probes for measurement of dc resistance on bottom section of forward entry door.

Figure 14- Forward - right view of the E-3A aircraft showing vertical tail fin panel.

Figure 15- View of the tail section of the E-3A aircraft, right side, showing vertical tail fin panel and corrosion area.

Figure 16- View of the tail section, left side, showing access panels for measuring transfer impedance.

Figure 17- Preparation of vertical tail fin panel, removal of paint to bare metal, for attachment of transfer impedance fixture

List of Figures (Continued)

Figure 18- Installation of transfer impedance fixture.

Figure 19- View of fixture and instruments for measuring transfer impedance.

Figure 20- Ground view of bottom side of rotodome and entry door.

Figure 21- Front view of air inlet duct EMP shield.

Figure 22- Comparison of measured Z_t using laboratory and field test fixtures (R_{dc} = 1 milliohm).

Figure 23- Comparison of measured Z_t using laboratory and field test fixtures (R_{dc} = 5 milliohms).

1.0 INTRODUCTION

At the present, chemical conversion coating (iridite) is used on the aluminum faying surfaces as the only protective finish that meets the EMP/EMI requirements. This procedure allows moisture to be trapped between the surfaces, resulting in severe corrosion. The nonconductive corrosion products that develop between these surfaces have proven to increase the impedance high enough to destroy the nuclear hardness of any weapon system.

An engineering study was performed by GTRI entitled Electromagnetic Pulse (EMP) and Electromagnetic Interference (EMI) Versus Corrosion Control Methods, 31 August 1987. The major conclusions from this investigation were:

A. Specially formulated, two-part liquid-applied sealants containing metal fillers with adjusted galvanic potentials can protect "bare" aluminum surfaces after 1000 hours of salt spray exposure per ASTM B117.

B. 2.5 milliohms of dc resistance can be maintained using selected sealants.

C. EMI/EMP shielding effectiveness is related to dc resistance and to the geometry of the structural bond.

This study was successful in that it formed relationships between shielding effectiveness, d.c. transfer impedance resistance and bond geometry. Also, it demonstrated that selected liquid-applied sealants were capable of protecting aluminum surfaces from corrosion while maintaining 2.5 milliohms of resistance across the bond. It was recommended that further research be conducted to identify multiple sealant materials and products that would protect a range of aircraft and weapon systems. Also, "real world testing" was encouraged to field test the sealants on actual aircraft and weapon systems. It was thought that the completion of these tasks would satisfy potential users of conductive sealants for structures requiring EMP/EMI hardening and corrosion protection. References a. - n. were consulted during the course of this project.

2.0 OBJECTIVES

2.1 Corrosion Prevention Materials and EMP/EMI Requirements

An objective was to evaluate the best corrosion prevention materials and processes to be compatible with the EMP/EMI requirements on aircraft.

2.2 Corrosion Prevention Materials and Nuclear Hardening

An objective was to determine the best corrosion prevention materials which will effectively protect against corrosion and provide nuclear hardness.

2.3 Field Testing

An objective was to determine the effects of a field level test performance of these materials on an actual weapon system in service.

2.4 Specification for Use of Conductive Sealants

An objective was to provide a draft military-type specification for the use of these materials on aircraft and weapons systems.

2.5 Qualified Products List for Conductive Sealants

An objective was to provide a draft military-type specification for the qualification of these materials for acquisition by the Air Force.

3.0 RESEARCH PLAN

The following tasks represent the research plan used for completion of the above objectives and the research project.

Task 1 - Preparation of Research Plans

Before the research was initiated, detailed plans, schedules, cost estimates, and functional assignments for analysis and test phases were prepared and submitted to the Sponsor. The research plan was submitted to the Sponsor thirty days after initiation of the contract. The Sponsor submitted to GTRI all comments on the research plan thirty days after receiving the plan. After an acceptable plan was agreed upon by both parties, the research was initiated.

The plan included input from the Sponsor and interested Air Force sources including, but not limited to, the following:

Mr. Sid Childers-MSA
Mr. Gary Stevenson-MSA
Mr. John C. Zentner-ASD/ENACE
Mr. George A. Slenski-MLSA

(continued from above)
Materials Integrity Branch
Systems Support Division
Air Force Wright Aeronautical Laboratories
Wright Patterson Air Force Base, Ohio

Mr. Calvin Moore-MMETM
Telephone (405) 736-5008
Headquarters Oklahoma City - Air Logistics Center
Materials Analysis Branch
Engineering Division
Tinker Air Force Base
Oklahoma 73145

Task 2 - Preparation of Test Joints and EMI/EMP Measurement Equipment

The test joints for the dc resistance and shielding effectiveness test setups were identical to those used in Reference m. In addition, a test fixture was designed and constructed to evaluate the transfer impedance of the test joints as in Reference m.

Chemical conversion coatings[j] over No. 7075 aluminum were be utilized before sealing since aluminum used for aircraft and weapon systems is usually treated with a chemical conversion coating.

Disbonds were intentionally designed into some of the joints to allow corrosive media access to the bond line and sealed conductive joint. Disbonds occur in the actual weapon systems. This procedure did better evaluate and measure the corrosive effects on electrical resistance and the extent of corrosion advancement between the conductive sealant-metal interface.

In the GTRI report, liquid-applied conductive sealants gave satisfactory corrosion resistance. Therefore, we proposed the continued use of these materials over the use of other methods as wire screen in primer coatings, inhibited conductive coatings, or gaskets. However, we did not eliminate these materials from the study. The application using liquid applied sealants is most economical and labor-saving.

Task 3 - Evaluation of Polymeric Conductive Sealants

This task consisted of the evaluation of polymeric sealants which had the potential of providing high conductivity and corrosion protection for aluminum surfaces. Conductive sealants consisted of a polymeric matrix filled with a conductive media,

e.g., silvered aluminum powder. The powder was dispersed within the liquid, uncured polymer to provide electrical conductivity in order to achieve the desired level of shielding effectiveness. Liquid, two-component polymeric matrix was required to maintain shelf life and avoid a moisture cure system which is not applicable for large joints. Fillers are required which possess galvanic potentials similar to that of aluminum so as not to produce a corrosive galvanic cell. Surface treatment of aluminum and blending fillers have been successful for this purpose. A matrix of polymeric materials and fillers with corresponding measured properties were prepared under this task. This task consisted of identifying a range of conductive sealant materials and testing them according to Task 4.

Task 4 - Accelerated Testing of Conductive Sealants

Accelerated testing of the sealed aluminum joints was performed per ASTM B117 and ASTM G-85-85 Salt Spray Chamber for a minimum of 2000 hours or until failure. Electrical dc resistance by the 4-point probe method, transfer impedance and shielding effectiveness was measured throughout the exposure time in the Salt Spray Chamber. Resistance, transfer impedance and shielding effectiveness versus exposure time was reported.

Task 5 - Plan for Conducting Field Tests

GTRI developed a test plan for conducting field tests on aircraft. The purpose of these tests was to evaluate the effectiveness in the field of selected conductive sealant materials with respect to corrosion and EMP/EMI requirements. First, several bare aluminum faying surfaces on each system were selected for application of the conductive sealant materials. Next, the resistance of each joint was measured with a double Kelvin bridge milliohmmeter before application of the sealant material. The conductive sealant material was then liquid-applied on the bare aluminum faying surfaces, cured, and the resistance of the joint was remeasured. The resistance of the joints was measured again after a one-year period.

Corrosion effects was determined by visual inspection and by field optical microscope with photographic capability. EMP/EMI effectiveness evaluation was nearly as straightforward as corrosion evaluation. DC resistance measurements are the most practical measurements which can be made for an actual installation (which is the primary reason why resistance is the parameter specified in MIL-B-5087B for evaluation of bond effectiveness by the contractor). As described above, dc resistance measurements were performed before and after application of the sealant materials and after a two-year period. Complicating the dc resistance measurement was the problem that

the actual resistance of the joint containing the conductive sealant materials was shorted out by either the conductive fasteners used to construct the joint or by a variety of other parallel paths set up by metallic structures which are in contact with both faying surfaces.

It should be noted (as described in the GTRI final technical report[m] on Contract No. F09603-85-R-0959) that the shielding effectiveness of a joint, and hence the effectiveness against EMP/EMI sources, cannot be determined simply from a knowledge of the dc resistance. A low dc resistance is not sufficient for good shielding effectiveness. Electrical continuity must be obtained across the entire joint area for effective shielding over a broad frequency range. This requirement is not necessarily met by a low dc resistance value nor was it to be verified solely by a dc resistance measurement. Consequently, measurements in addition to the required dc resistance measurements were beneficial in terms of evaluating the effectiveness of the conductive sealants with respect to EMP/EMI requirements.

Additional means of characterizing the bonding effectiveness of conductive sealants included shielding effectiveness measurements and transfer impedance measurements. Shielding effectiveness testing is the most direct method of evaluating conductive sealants performance with respect to EMP/EMI requirements. However, in certain instances, shielding effectiveness testing may not be feasible. For example, adequate room may not exist inside of a missile to place the receiving antenna which is required to perform standard (e.g. MIL-STD-285) shielding effectiveness measurements. Another difficulty surrounds the fact that illumination of the system during shielding effectiveness measurements will expose other shield flaws which will make isolation of the joint-under-test extremely difficult or impossible. Consequently, the use of shielding effectiveness measurements were carefully assessed in terms of its feasibility and applicability to bonding effectiveness evaluation of the conductive sealant materials.

An approach which was applicable to the present problem is to measure the transfer impedance of the conductive sealant bonds over a wide frequency range. Transfer impedance measurements made over a broad frequency range and at several different points along the length of the joint would provide a better indication of bond effectiveness than a dc resistance measurement. Relative comparisons were made between bonds with conductive sealants applied versus those without conductive sealants applied.

GTRI proposed to perform the required dc resistance measurements and to supplement these measurements with additional measurements which more effectively evaluated the effectiveness of the sealant materials in protecting against EMP/EMI sources.

Selection of the particular joints to be tested included consideration as to the testability of the joint from both a dc resistance and an transfer impedance/shielding effectiveness measurement perspective. The existence of parallel conducting paths were identified and documented, and their impact on the dc resistance measurements was assessed.

Task 6 - Visits to Air Force Installations

GTRI personnel visited the Oklahoma Air Logistics Center in order to conduct field testing on identified aircraft. The first visit to this installation was made early in the program. During this first visit, the panels/joints were selected and all necessary information regarding these panels (such as location, total faying surface area, fastening technique, number of fasteners, existence of parallel conducting paths, etc.) were obtained for test planning purposes. After the test plans were complete, a second visit was made to apply the sealant materials and to make the electrical performance measurements both before and after application of the sealants. The third visit was planned to be made one year after the second visit to re-evaluate the performance of the conductive sealant materials. However, the final inspection was not possible for 24 months since the plane was on mission.

Personnel who directly assisted GTRI at OC-ALC were:

Lt. James Kihle
U.S. Air Force/OC-ALC/MMKRA
(405) 736-2748
DSN: 336-2748

Frank J. Parker
(OC-ALC/MMKRA)
(405) 736-2748
DSN: 336-2748

Pam Kennedy
(OC-ALC/MMKRA)
(405) 736-3660
DSN: 336-3660

The areas that were selected on the E-3A aircraft for testing of the conductive sealants are listed below and are shown in relationship to the aircraft in Figures 1 and 2.

a. Vertical Tail Fin (see Figures 3 and 4)

Corrosion in the form of pitting around the fastening surfaces of the fin have been regularly observed.

b. Forward Entry Door (see Figure 5)

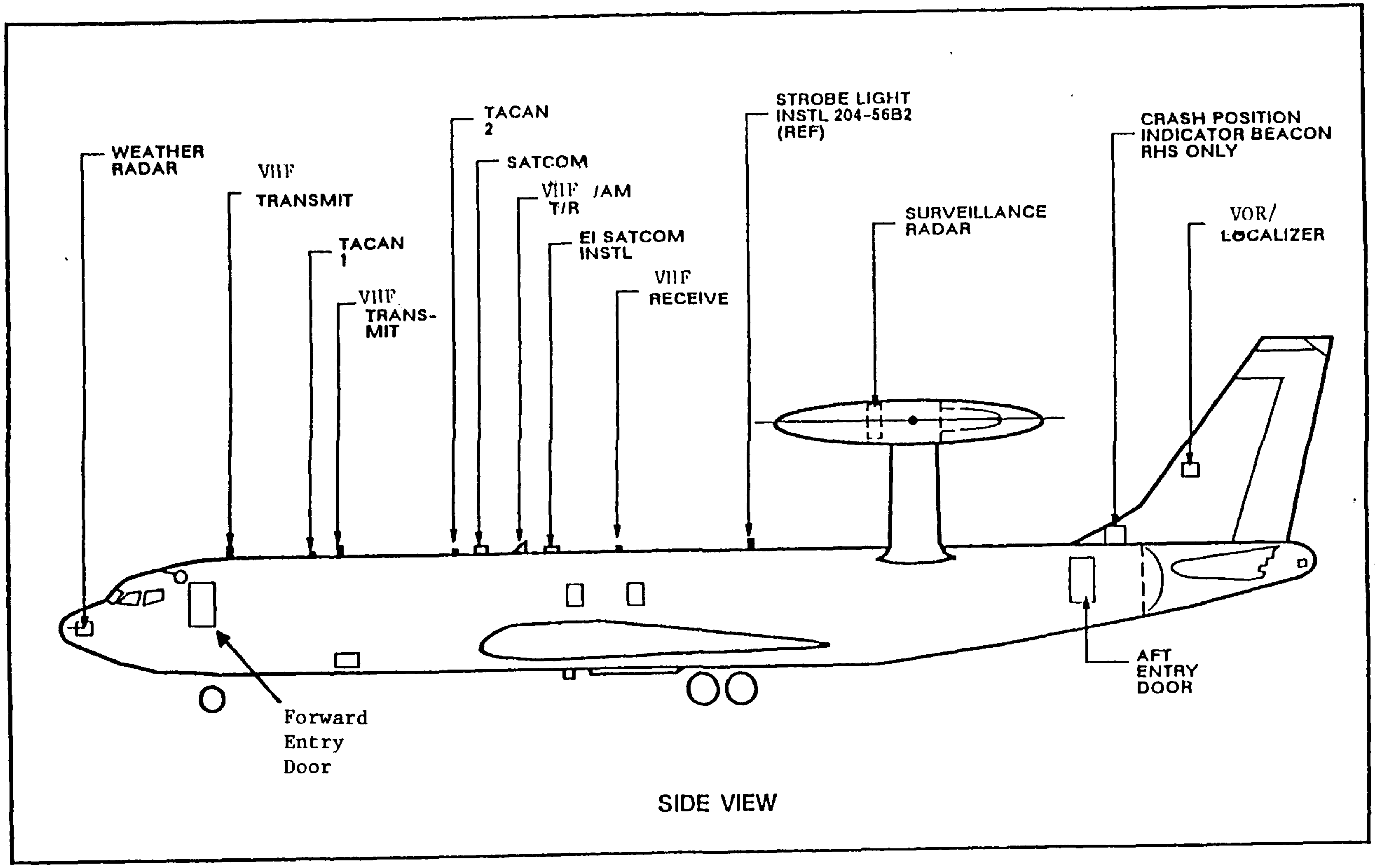


FIGURE 1. PROFILE OF E-3A AIRCRAFT

jg.A8245.000-2

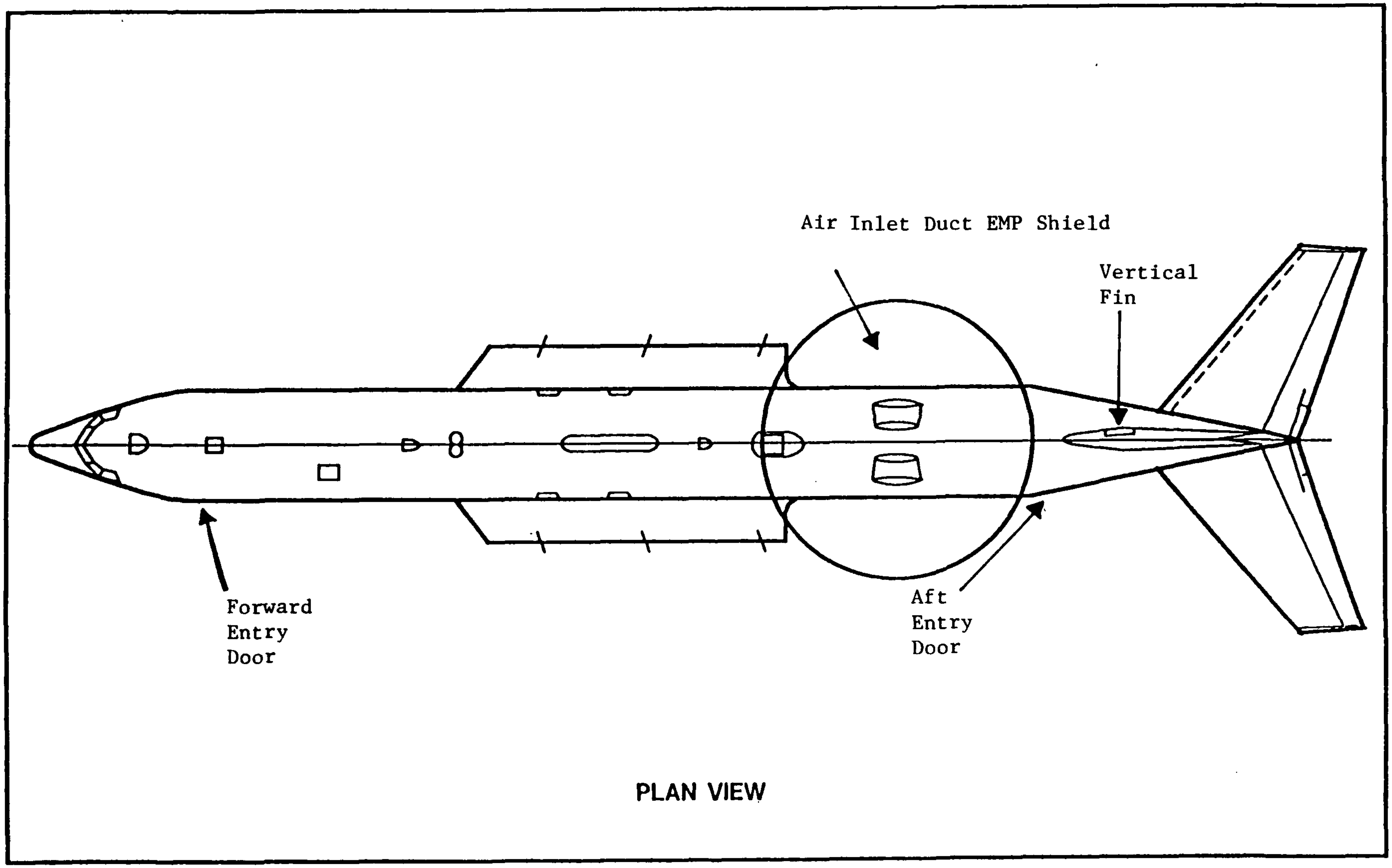


FIGURE 2. TOP VIEW OF E-3A AIRCRAFT

jg.A8245.000-1

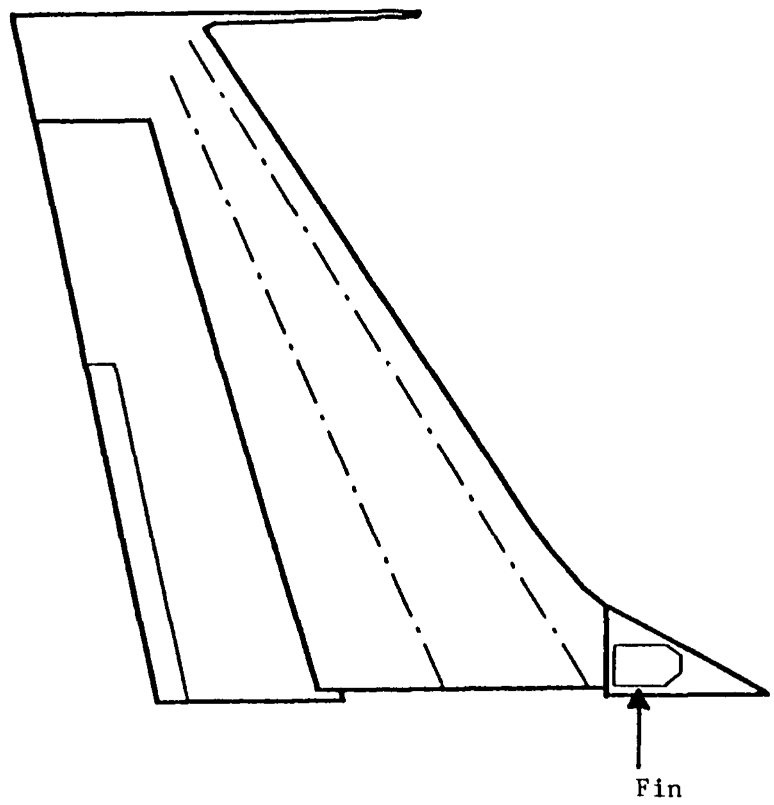


FIGURE 3. PATCH, VERTICAL FIN

lg.A8245.000-4

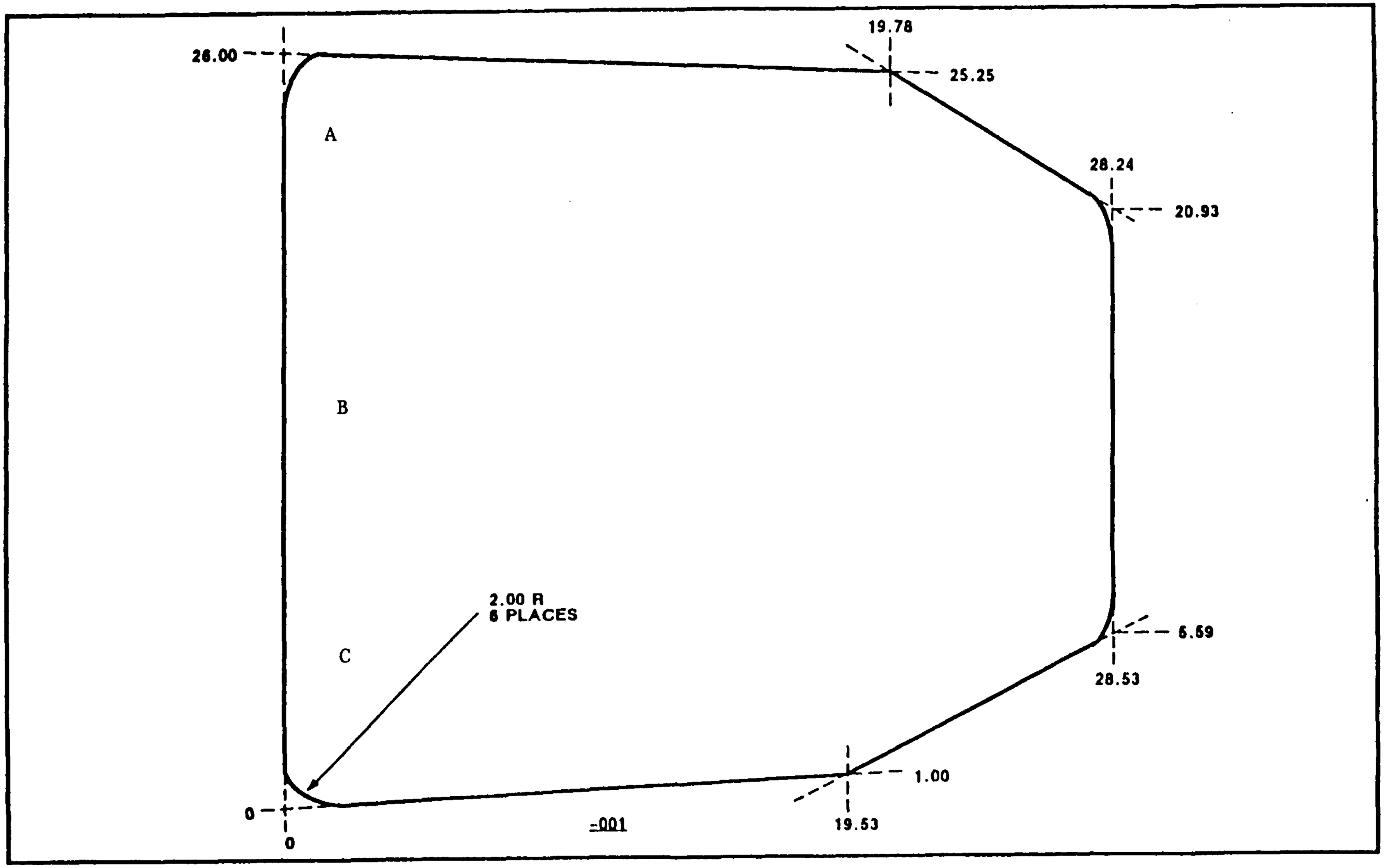


FIGURE 4. PATCH PANEL DIMENSIONS

Jg.A8245.000-3

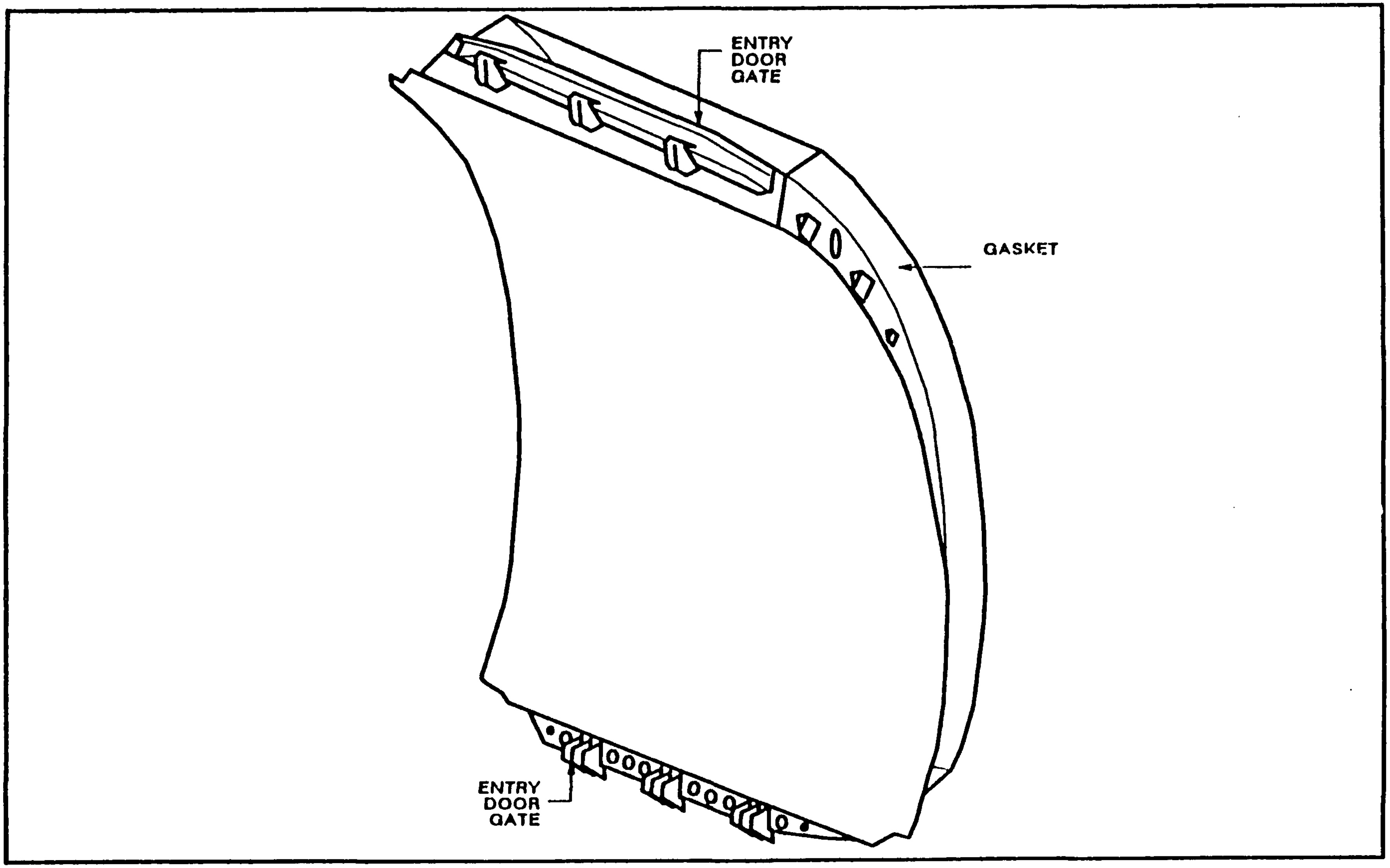


FIGURE 5. E-3A AFT ENTRY DOOR

jg. A8245.000 - 8.

Severe pitting adjacent to the elastomeric gasket has been regularly observed, especially on the bottom sections where condensation collects.

c. Aft Entry Door (see Figure 5)

(Same as in b.)

d. Rotodome Air Inlet Duct EMP Shield (see Figure 2)

The vent has been observed to corrode badly and produce larger passages due to failure of the metal.

All of these areas have exhibited documented notorious corrosion problems. The bonds in these area all require electrical conductivity. GTRI theorized that, if the proposed conductive sealants could solve the corrosion problem, then the electrical conductivity could be maintained as well as maintaining the electromagnetic shielding.

Task 7 - Preparation of Sealant Material Specification and Qualified Products List.

After Tasks 1-6 were completed and data was accumulated and analyzed, then a draft, military type performance specification was prepared for Air Force use. This was followed by a draft, qualified products lists for these materials. Also, an AMS specification based on the results of this work was prepared.

4.0 RESULTS AND DISCUSSION

4.1 Evaluation of Laboratory Sealant Test Samples

The dc resistance, shielding effectiveness, and transfer impedance of each test sample were measured. The shielding effectiveness and transfer impedance plots are contained in Appendix A and Appendix B, respectively. Three different materials were evaluated: (1) Chomerics 4375-27-4, (2) PRC 1764 A-2, and (3) PRC 1764 Class B. Four samples of each material were evaluated for a total of twelve different test samples. Iridited aluminum substrates were used in three of the four samples whereas one of the four samples was assembled with bare aluminum substrates. The test samples were coded for identification purposes as listed in Table 1.

The electrical measurements were made shortly after the test samples were assembled and the sealants were cured. Next, the samples were placed in a salt-fog chamber for accelerated corrosion testing. The samples were periodically removed from

the salt-fog chamber (ASTM B 117), dried, and the surfaces which contact the electrical test fixtures were cleaned. The dc resistance measurements were performed at approximately one week intervals. The transfer impedance and shielding effectiveness measurements were repeated at approximately two week intervals with a total salt fog exposure time of 2000 hours. A brief description of the dc resistance, shielding effectiveness, and transfer impedance measurement techniques are briefly described below.

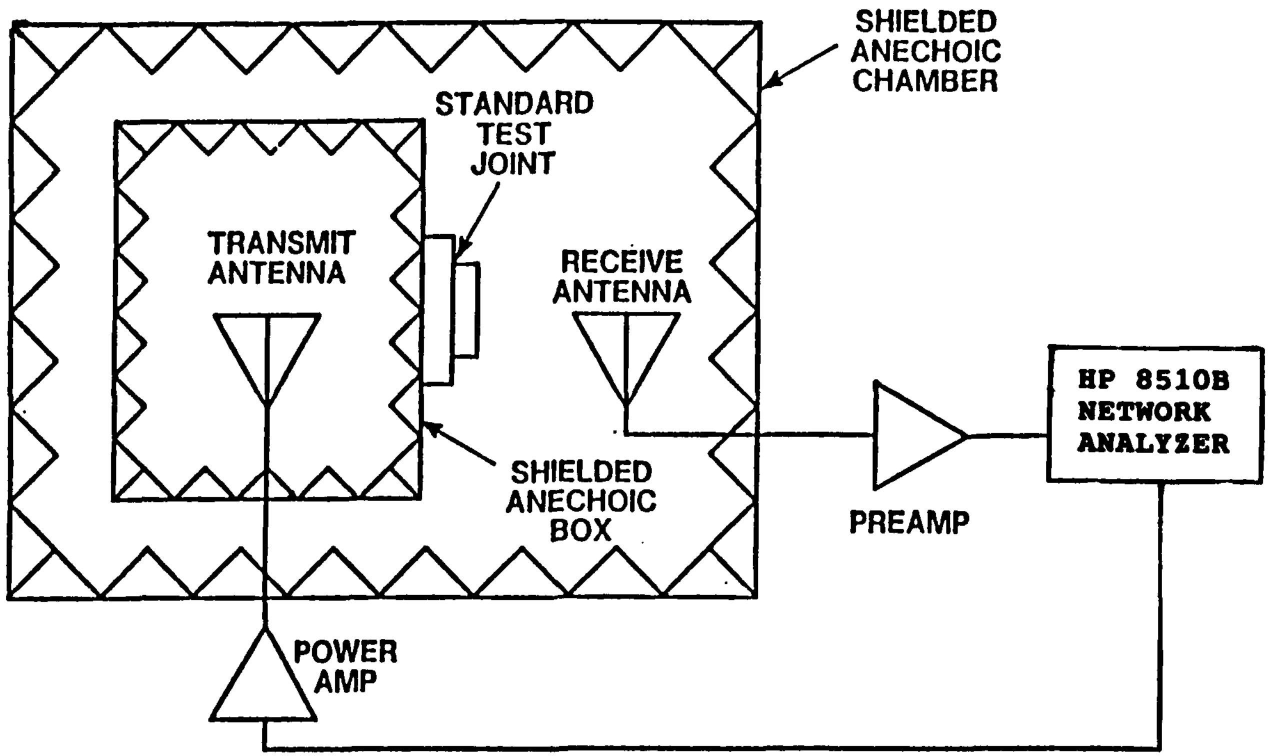
4.1.1 DC Resistance Measurements

The dc resistance of the test samples was measured with a double Kelvin bridge milliohmmeter. The double Kelvin bridge (General Electric Mfg.) is a four terminal instrument which is capable of accurately measuring very small resistance values (in this case, as low as 0.1 mΩ). The terminals of the milliohmmeter were clipped or contacted directly to the metal plates of the test joint. All resistance measurements were made after the sealant material had cured so that the resistance value had time to stabilize.

4.1.2 Shielding Effectiveness Measurements

The shielding effectiveness of each test sample was determined as the difference (in dB) between the electromagnetic field coupled through an aperture with and without the sample present over the aperture. (This measurement technique conforms to the basic procedure set forth in MIL-STD-285[n].) A block diagram of the shielding effectiveness test setup is illustrated in Figure 6. This test setup enabled accurate and repeatable swept frequency measurements to be made on the test joint samples over the 500 - 1000 MHz frequency range. A transmitting antenna (capacitively-loaded dipole) was placed in the center of a shielding effectiveness test enclosure and a receiving antenna (log conical spiral) was positioned outside of the test enclosure at a distance (5 1/2 feet) which meets the far-field criterion over the entire test frequency range. The log conical spiral receiving antenna was directed towards a 6 inch square aperture located in one wall of the enclosure. The purpose of the test chamber was to isolate the transmitting and receiving antennas such that the only coupling between them was through the aperture. To minimize unwanted coupling, all permanent seams of the test enclosure are welded and finger stock is installed around the lid of the enclosure and around the periphery of the test panel port (aperture). The inside of the test enclosure was lined with ferrite absorbing tiles which serve to dampen enclosure resonances and to simulate free-space conditions for the transmitting antenna.

The test joint was fastened to the test enclosure and electromagnetically sealed by three rows of finger stock located



$$S.E.\ (dB) = 10\ LOG\ [P_R(\text{WITHOUT SAMPLE}) / P_R\ (\text{WITH SAMPLE})]$$

Figure 6. Block diagram of the shielding effectiveness test setup.

on the enclosure flange area. Conductive copper tape was also applied around the periphery of the test sample as an additional precautionary measure to prevent the electromagnetic field from leaking around, rather than through, the test sample. A 6-dB attenuator was used at the transmitting antenna input port to ensure a stable 50-ohm impedance at the power amplifier output. An HP 8510B network analyzer was used to provide the swept frequency output source and receiver. The power amplifier provided approximately 46 dB of RF gain which corresponded to 4 watts output power with -10 dBm (-10 decibels relative to 1.0 milliwatt) input power. A low noise, high gain amplifier (noise figure = 2 dB; gain = 35 dB) was used to improve the sensitivity of the spectrum analyzer and thereby increase the overall dynamic range.

The test enclosure and receiving antenna were located in a shielded anechoic chamber in order to isolate the test antennas from the external electromagnetic environment and to minimize errors due to ground and/or wall reflections. The isolation characteristics of this chamber were 100 dB or greater over the frequency range of 10 MHz to 1000 MHz and absorption was effective for RF frequencies greater than 300 MHz. The test enclosure was connected to the outside of the anechoic chamber via a 1/2 inch copper pipe/flange assembly and a coaxial cable was routed through the copper pipe to connect the power amplifier outside the enclosure to the attenuator and transmitting antenna located inside the test enclosure. This cable routing configuration was used to prevent RF energy from coupling the coaxial cable to the receiving antenna and swamping the signal which is coupled through the test sample. In this way, a dynamic range of approximately 100 dB was achieved. (The dynamic range of the test setup is the ratio of the signal level coupled to the receiving antenna with the aperture open to the signal level received with a thick metal plate fastened over the aperture.)

4.1.3 Transfer Impedance Measurements

One measure of the RF performance of shielding materials (sealants, EMI gaskets, etc.) is surface transfer impedance. Electromagnetic fields incident on the exterior of a shield induce surface currents. When these surface currents encounter an imperfectly sealed aperture or seam, a voltage is induced across the seam on the interior of the shield. These interior voltages then act as secondary sources and reradiate internal to the shield thereby degrading the performance of the shield. The transfer impedance of the conductive sealant joint may be defined as follows:

$$Z_t = \frac{V_o}{J_s} \qquad (1)$$

where:

Z_t = transfer impedance (in $\Omega \cdot m$);
V_o = induced output voltage (in V); and
J_s = surface current density (in A/m).

The transfer impedance of each test sample was measured using a transfer impedance test fixture. The drawings for the test fixture, which has an upper frequency limit of 200 MHz, are provided in Appendix C. A block diagram of the overall transfer impedance test setup is shown in Figure 7. The transfer impedance was measured over the 100 kHz to 200 MHz frequency range with an HP 3577A network analyzer. The RF output of the network analyzer was terminated in a matched 50 ohm load resistor. The Reference Channel of the network analyzer was used to measure the input voltage which was then used to calculate the current flowing through the 50 ohm resistor and, thus, the test sample. Channel A of the network analyzer was used to measure the voltage induced across the test sample. The transfer impedance was then found by dividing the voltage induced across the test sample by the current flowing through the test sample. All mathematical operations were performed by the network analyzer. The transfer impedance as a function of frequency was plotted on a digital plotter. An IBM compatible PC computer was used to control all test instrumentation.

The transfer impedance data is presented in units of dBΩ. In order to compare the data with other data measured using test fixtures with different dimensions, one must convert this data to units of $\Omega \cdot m$. Since the perimeter of the test joint was approximately 53 cm, it was necessary to subtract 5.5 dB (20 log 0.53) from the data presented in the plots to yield the normalized transfer impedance.

4.1.4 Relationship of Transfer Impedance to Shielding Effectiveness

Shielding effectiveness is dependent on many variables including the properties of the shield (shield geometry, seam dimensions, seam orientation) as well as the properties of the electromagnetic wave (impedance, polarization, and incidence angle). Therefore, the relationship between Z_t and SE can be extremely complex for practical shield geometries and field conditions. However, as a simple rule of thumb, the following relationship was used:

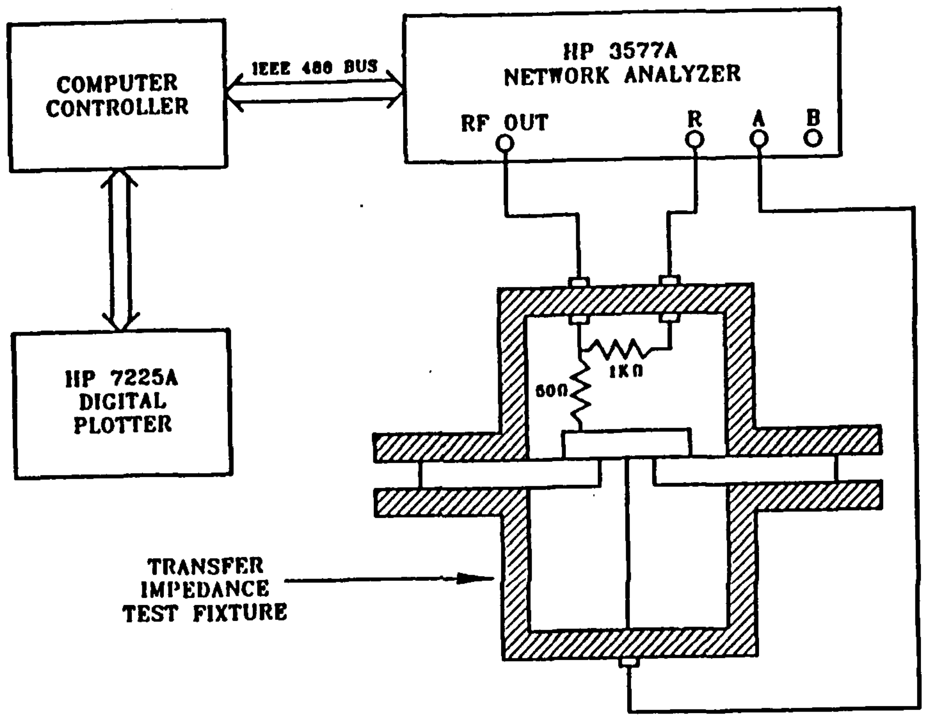


Figure 7. Block diagram of the transfer impedance test setup.

$$SE(dB) = 22.5 - Z_t(dB\Omega \cdot m) \quad (2)$$

The constant (22.5 dBΩ·m) in Equation 2 was empirically derived from the measured data and thus applies to the particular geometry and field conditions used during our tests. Since the upper frequency limit of the transfer impedance measurements was 200 MHz and the lower frequency limit of the shielding effectiveness measurements was 500 MHz, the 200 MHz transfer impedance data was extrapolated to 500 MHz using the 200 MHz amplitude and slope. The constant in Equation 2 was then calculated for each test sample by adding the 500 MHz shielding effectiveness value to the extrapolated 500 MHz transfer impedance value. The resultant values were then statistically analyzed to have an average value of 22.5 dBΩ·m and a standard deviation of 3.0 dB. As an example, Sample A2 (t = 377 hrs) had a transfer impedance of -52.5 dbΩ at 200 MHz and an extrapolated transfer impedance of -50 dbΩ at 500 MHz. Normalizing this extrapolated impedance by the perimeter length yielded a transfer impedance of -55.5 dBΩ·m which, when inserted in Equation 2, yielded a predicted shielding effectiveness at 500 MHz of 78 dB. This predicted value was close to the measured shielding effectiveness value for A2 at 500 MHz of 75 dB.

4.1.5 Laboratory Test Results

D. C. Resistance Test Results

A summary of the dc resistance test results is provided in Table 2. The Chomerics 4375-27-4 samples provided reasonably good performance. The dc resistance values for the iridited samples (A1, A2, and A3) were initially in the range of 0.42 - 0.67 mΩ and gradually increased with salt-fog exposure time to 1.17 - 2.50 mΩ at 2000 hours. The non-iridited sample (A-4) initially had an immeasurably low resistance (< 0.1 mΩ), but the resistance increased to 28 mΩ after 2000 hours. The PRC 1764 A-2 sealant samples provided excellent performance. The dc resistance values for both the iridited samples (C1, C2, and C3) and the non-iridited sample (C4) were consistently less than 1.5 mΩ through the duration of the testing and were typically less than 0.1 mΩ. The PRC 1764-B sealant samples also provided excellent performance. The dc resistance values for both the iridited samples (D1, D2, and D3) and the non-iridited sample (D4) were consistently less than or equal to 1.3 mΩ through the duration of the testing and were often times less than 0.1 mΩ.

Shielding Effectiveness Test Results

A summary of the shielding effectiveness test results is provided in Table 3. The shielding data was averaged over the 500 - 1000 MHz frequency range and this average shielding value was used in the summary table. The Chomerics 4375-27-4 samples provided reasonably good shielding performance over the 2000 hour salt-fog test period. The average shielding effectiveness values for the iridited samples (A1, A2, and A3) were initially in the range of 76 to 88 dB and gradually decreased with salt-fog exposure time to 61 - 73 dB at 2000 hours. The non-iridited sample (A-4) initially had an immeasurably high shielding effectiveness value (> 90 dB) but the shielding decreased rapidly with salt-fog exposure to a value of 55 dB after 2000 hours. The PRC 1764 A-2 sealant samples provided excellent shielding performance. The shielding effectiveness values for both the iridited samples (C1, C2, and C3) and the non-iridited sample (C4) exceeded the measurement dynamic range (> 90 dB) through the duration of the testing. The PRC 1764-B sealant samples also provided excellent shielding performance. The shielding effectiveness values for both the iridited samples (D1, D2, and D3) and the non-iridited sample (D4) were consistently greater than 90 dB for the duration of the test period.

Transfer Impedance Test Results

A summary of the transfer impedance test results is provided in Table 4. Separate entries are provided for 100 kHz (lowest test frequency) and 200 MHz (highest test frequency). Note that the low frequency (i.e., 100 kHz) transfer impedance corresponds to the dc resistance of the test joint. The Chomerics 4375-27-4 samples provided reasonably good performance. The transfer impedance values for the iridited samples (A1, A2, and A3) were initially in the range of -65 to -54 dBΩ (0.6 - 2.0 mΩ) and gradually increased with salt-fog exposure time to -59 to -36 dBΩ (1.1 - 15.8 mΩ) at 2000 hours. The non-iridited sample (A-4) initially had transfer impedance values of -87 (or less) to -79 dBΩ (0.04 - 1.1 mΩ) but the transfer impedance increased rapidly to a range from -32 to -22 dBΩ (25.1 - 79.4 mΩ) after 2000 hours. The PRC 1764 A-2 sealant samples provided excellent performance. The transfer impedance values for both the iridited samples (C1, C2, and C3) and the non-iridited sample (C4) ranged from -99 to -70 dBΩ (0.01 - 0.3 mΩ) and showed very little degradation in performance after 2000 hours. The PRC 1764-B sealant samples also provided excellent transfer impedance performance. The transfer impedance values for both the iridited samples (D1, D2, and D3) and the non-iridited sample (D4) ranged from -91 to -68 dBΩ (0.03 - 0.4 mΩ) and showed very little degradation in performance after 2000 hours.

4.2 Field Test Measurements

4.2.1 Location of Test Sites

The test sites on the E-3A aircraft are shown in Figure 1-6, and actual photographs of the test sites are attached.

Figure 8- Front left view of E-3A aircraft showing forward and aft entry doors.

Figure 9- View of the bottom section of the forward entry door and corrosion areas.

Figure 10- View of forward door, bottom view of sealing gasket and corrosion areas.

Figure 11- View of open aft entry door.

Figure 12- View of bottom section of the aft entry door and corrosion areas.

Figure 13- Installation of probes for measurement of dc resistance on bottom section of forward entry door.

Figure 14- Forward - right view of the E-3A aircraft showing vertical tail fin panel.

Figure 15- View of the tail section of the E-3A aircraft, right side, showing vertical tail fin panel and corrosion area.

Figure 16- View of the tail section, left side, showing access panels for measuring transfer impedance.

Figure 17- Preparation of vertical tail fin panel, removal of paint to bare metal, for attachment of transfer impedance fixture.

Figure 18- Installation of transfer impedance fixture.

Figure 19- View of fixture and instruments for measuring transfer impedance.

Figure 20- Ground view of bottom side of rotodome and entry door.

Figure 21- Front view of air inlet duct EMP shield.

DC resistance and transfer impedance measurements were performed on the E-3A aircraft (Tail No. 77-351). In order to perform the transfer impedance measurements in the field, a specialized field transfer impedance test fixture was designed and fabricated. A photograph of the field test fixture is shown in Figure 18. In order to validate the functionality of the field test fixture, transfer impedance measurements on laboratory samples were performed with both the laboratory and field test fixtures. Comparative plots of the lab and field test fixtures for high impedance (R_{dc} = 1 Ω) and low impedance (R_{dc} = 5 mΩ) test samples are shown in Figures 22 and 23, respectively. Note that the close agreement occurs at low frequencies where the "effective" perimeter is essentially the same for both fixtures. However, at high frequencies, the field test fixture essentially concentrates surface current over a smaller region resulting in an increase in impedance of approximately 10 dB (implying a reduction in effective perimeter from the lab fixture value of 0.53 m to a value of 0.17 m). Overall, the field test fixture provides reasonable and accurate transfer impedance data, particularly when the reduction in effective perimeter is taken into account.

4.2.2 E-3A Field Test Results

The test areas on the E-3A aircraft are listed in Table 5 with respect to the type of conductive sealant used. The results of a visual inspection using a field microscope are contained in Table 6. Significant corrosion and pitting was observed during the initial inspection. All surfaces were lightly abrasively cleaned with sand paper to remove products of corrosion before applying the conductive sealants. After 24 months, the same surfaces were reinspected and no indications of corrosion were present in all cases.

The dc resistance measurements generally indicate that the conductive sealants maintained conductance and prevented corrosion. However, there are some measurements which require explanation. The aft entry door did not show corrosion after 24 months of service in contrast to the initial inspection, but the dc resistance rose to 4.6 milliohms in one measurement. First, the dc resistance measurements are actually a measurement across the metal fasteners where no sealant was used; and measurement across sealant and fasteners after 24 months. Severe corrosion was observed initially and none after 24 months. Considering these circumstances, GTRI believes that the 1.4-4.6 milliohm measurement is an indication of good conductivity and corrosion prevention although 2.5 milliohms and below would be preferred.

Referring to the air vent EMP shield, GTRI cleaned the surfaces from products of corrosion, applied conductive sealant to these surfaces and remounted the shield which had some severe damage in the center section. Measurements were made and

reported as shown in Table 7. After the measurements were made, the shield was removed, and the corroded section replaced using nonconductive sealant by maintenance workers at OC-ALC. The 11.3 milliohm measurement is explained by the presence of nonconductive sealant on the surfaces and around the fasteners. No additional corrosion was observed.

The transfer impedance data for the tail panel measurements are provided in Appendix D. Note that when the tail panel was assembled with the Chomerics 4375-27-4 sealant, the anodized (nonconductive) finish was inadvertently left on prior to application of the sealant. Thus, the only conductivity from the panel to the aircraft was through the rivet fasteners leaving nonconductive slots which are indicated by the inductive impedance (Z_t increases monotonically with frequency) noted in all of the plots. However, very little change in transfer impedance was noted over the 2 year period between measurements indicating that the conductive sealant provided excellent corrosion prevention characteristics.

5.0 CONCLUSIONS

The conclusions which may be drawn from this study are based on the previous laboratory study, Electromagnetic Pulse and Electromagnetic Interference Versus Corrosion Protection Methods (31 August 1987), and the above field report. The above field study utilized the successful conductive sealant materials for application on an E-3 aircraft. Visual inspection, and electrical measurements including d.c. resistance and transfer impedance, were performed on four corrosion prone areas to measure the effectiveness of the sealant materials.

The conclusions follow:

A. Visual corrosion was arrested on all areas tested using both conductive sealant materials.

B. Transfer impedance and d.c. resistance measurements indicated that the corrosion was arrested in all test areas.

C. Corrosion was successfully monitored using d.c. resistance and transfer impedance; a correlation was made.

D. The 2.5 milliohm d.c. resistance requirement is achievable using conductive sealants and for up to at least 24 months of field service.

E. Salt spray (ASTM B117) testing on test panels correlate to field results; the accelerated method is a an acceptable method of evaluating materials for this application.

F. The use of the proven conductive sealants have the potential of saving the Air Force significant maintenance time in replacing parts and costs of parts/materials.

6.0 RECOMMENDATIONS

Based on the successful results of the above report and those reported in reference m., we recommend the following:

A. Use of the tested sealant materials on corrosion - prone joints and bonds which require the dc 2.5 milliohm dc resistance. GTRI feels comfortable in recommending these materials for extensive use on equipment which will result in significant saving in parts replacement maintenance.

Applicable equipment could include:

1. aircraft
2. missiles
3. electronic/communications equipment
4. ground equipment

B. Pretesting and evaluation of sealant materials using the the GTRI test joints and methods.

C. GTRI strongly recommends an advanced field study using conductive sealants extensively on test aircraft to confirm the cost saving advantages of corrosion inhibiting and conductive polymeric sealant.

D. A specification (see Appendix E) that is refined and developed for acquisition use; and an American Materials Specification (AMS) developed from this specification.

7.0 REFERENCES

a. TO 1-1-1, Cleaning of Aerospace Equipment. (Basic Issue. 29 Jun 79, Change 18, 3 Sep 87).

b. TO 1-1-2, Corrosion Prevention and Control by Aerospace Equipment. (Basic Issue, 3 March 83, Change 7, 16 Apr 87).

c. AFSC Design Handbook 1-4, Electromagnetic Compatibility. (January 1987).

d. MIL-STD-454J, Standard General Requirements for Electronic Equipment, 26 Feb 87.

e. MIL-STD-461C, Electromagnetic Emission and Susceptibility Requirements for the Control of Electromagnetic Interference, 1 Apr 87.

f. MIL-STD-462, Electromagnetic Interference Characteristics Measurement of: 9 Feb 71.

g. MIL-STD-469, Radar Engineering Design Requirements, Electromagnetic Compatibility: 30 Mar 67.

h. MIL-HDBK-253, Guidance for the Design and Test of Systems Protected Against the Effects of Electromagnetic Energy, 28 Jul 78.

i. MIL-S-5002C, Surface Treatments and Inorganic Coatings for Metal Surfaces of Weapons Systems, 28 Aug 78.

j. MIL-C-5541, Chemical Conversion Coatings on Aluminum Alloys, 14 Apr 81.

k. MIL-STD-889B, Dissimilar Metals, 21 Nov 79.

l. MIL-STD-1568A, Materials and Processes for Corrosion Prevention and Control in Aerospace Weapons Systems, 24 Oct 79.

m. "Electromagnetic Pulse and Electromagnetic Interference Versus Corrosion Protection Methods," by Georgia Tech Research Institute, Atlanta, GA, 31 Aug 87.

n. MIL-STD-285, "Attenuation Measurements for Enclosures, Electromagnetic Shielding, for Electronic Test Purposes, Method of," 25 Jun 56.

Table 1. Test Joints and Identification

Test Joint No.	Sample No.	Joint Surface Coating	Sealant/Part Identification
1	A1	Iridite	Chomerics 4375-27-4
2	A2	Iridite	"
3	A3	Iridite	"
4	A4	None	"
5	C1	Iridite	PRC 1764 A-2
6	C2	Iridite	"
7	C3	Iridite	"
8	C4	None	"
9	D1	Iridite	PRC 1764 Class B
10	D2	Iridite	"
11	D3	Iridite	"
12	D4	None	"
13	B1	Iridite	Control (No sealant)
14	B2	None	"
15	B3	Iridite	Chomerics 4375-27-4

Table 2. D.C. Resistance (milliohms) of Test Samples

		Milliohms											
Sealant	Sample	Hours of Salt Spray Exposure											
		0	164	377	517	681	800	960	1124	1264	1428	1572	2000
Chomerics 4375-27-4	A1	0.67	0.71	0.92	0.80	0.89	0.93	0.97	0.98	1.06	1.10	1.20	1.59
	A2	0.47	0.80	0.73	0.52	0.69	0.77	0.96	1.02	1.12	1.12	1.46	2.50
	A3	0.42	0.70	0.70	1.15	0.62	0.66	0.74	0.71	0.77	0.80	0.86	1.17
	A4	<.1	0.23	0.22	<.1	<.1	<.1	0.10	0.10	0.17	0.21	0.29	28
PRC 1764 A-2	C1	0.11	1.10	0.30	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1
	C2	<.1	1.47	0.35	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1
	C3	0.14	0.24	0.37	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1
	C4	<.1	0.18	0.37	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1
PRC 1764 Class B	D1	0.36	1.30	0.20	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1
	D2	0.17	0.43	0.18	<.1	<.1	<.1	<.1	0.12	0.12	0.17	0.18	0.1
	D3	<.1	0.45	0.14	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1
	D4	<.1	0.15	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1
					468	612	1285 Hrs.						
None	B1	0.15	0.15	0.18	<.1	0.23	0.31						
None	B2	<.1	<.1	0.21	0.24	0.68	>22,000						
Chomerics 4375-27-4	B3	0.38	0.40	0.41	0.42	0.45	0.50						

Non-iridited surfaces - A4, C4, D4, and B2.

Table 3. Average Shielding Effectiveness (dB) of Test Samples

Sealant	Sample No.	Hours of Salt Spray Exposure						
		0	377	681	960	1264	1572	2000
Chomerics 1375-27-4	A1	76	76	75	75	75	73	71
	A2	88	72	70	67	67	66	61
	A3	88	78	79	77	77	75	73
	A4	90^L	90^L	90^L	82^L	69	63	55
PRC 1764 A-2	C1	90^L	90^L	90^L	90^L	90^L	90^L	90^L
	C2	90^L	90^L	90^L	90^L	90^L	90^L	90^L
	C3	90^L	90^L	90^L	90^L	90^L	90^L	90^L
	C4	90^L	90^L	90^L	90^L	90^L	90^L	90^L
PRC 1764-B	D1	90^L	90^L	90^L	90^L	90^L	90^L	90^L
	D2	90^L	90^L	90^L	90^L	90^L	90^L	90^L
	D3	90^L	90^L	90^L	90^L	90^L	90^L	90^L
	D4	90^L	90^L	90^L	90^L	90^L	90^L	90^L
			<u>304</u>	<u>612</u>		<u>1285 Hrs.</u>		
None	B1	87	90^L	85		90		
None	B2	90^L	75	63		72		
Chomerics 4375-27-4	B3	75	75	75				

Note - Entries with "L" indicate that the reading was limited by the dynamic range of the test set-up, and that the actual shielding effectiveness was probably <u>greater</u> than the reported value.

Table 4. Transfer Impedance (dB-Ohm) of Test Samples

Salt Spray Exposure, Hours		0		377		681		960	
Test Frequency,		100 kHz	200 MHz	100 kHz	200 MHz	100 kHz	200 MHz	100 kHz	200 MHz
Sealant	Sample								
Chomerics 4375-27-4	A1	-61	-54	-61	-52.5	-58	-51	-58	-51
	A2	-65	-61	-64	-44	-61	-39	-57	-36
	A3	-63	-60	-64	-56	-61	-54	-61	-54
	A4	-87^{L}	-79	-78^{L}	-75^{L}	-78	-65	-75	-58
PRC 1764 A-2	C1	-76	-95^{L}	-77^{L}	-91^{L}	-72	-85^{L}	-72	-77^{L}
	C2	-79	-89^{L}	-77^{L}	-79^{L}	-76	-79^{L}	-76	-85^{L}
	C3	-79	-91^{L}	-75^{L}	-83^{L}	-76	-86^{L}	-70	-82^{L}
	C4	-83^{L}	-99^{L}	-79^{L}	-79^{L}	-79	-79^{L}	-73^{L}	-75^{L}
PRC 1764-B	D1	-71	-87^{L}	-70	-83^{L}	-68	-85^{L}	-69	-82^{L}
	D2	-72.5	-82^{L}	-72	-82^{L}	-71	-82^{L}	-68	-72^{L}
	D3	-76^{L}	-81^{L}	-74	-87^{L}	-76	-83^{L}	-73	-74^{L}
	D4	-91^{L}	-88^{L}	-79^{L}	-79^{L}	-84^{L}	-83^{L}	-78^{L}	-73^{L}
		0		304		612 Hrs.			
None	B1	-71	-60	-71	-60	-70	-57		
None	B2	-77^{L}	-68^{L}	-71	-42	-57	-34		
Chomerics 4375-27-4	B3	-63	-51	-68	-47	-67.5	-51		

Note - Entries with a "^{L}" indicate that the reading was limited by the measurement sensitivity and that the transfer impedance was probably <u>lower</u> (i.e., more negative) than the entered value.

Table 4. Transfer Impedance (dB-Ohm) of Test Samples (Continued)

Salt Spray Exposure, Hrs.		1264		1572		2000	
Test Frequency,		100 kHz	200 MHz	100 kHz	200 MHz	100 kHz	200 MHz
Sealant	Sample						
Chomerics 4375-27-4	A1	-60	-51	-59	-51	-56	-48
	A2	-58	-36	-57	-37	-52	-36
	A3	-62	-53	-61	-53	-59	-52
	A4	-75	-43	-67	-38	-32	-22
PRC 1764 A-2	C1	-82^L	-83^L	-82^L	-92^L	-79	-87^L
	C2	-83^L	-80^L	-86^L	-96^L	-80	-83^L
	C3	-79^L	-79^L	-85^L	-96^L	-78	-88^L
	C4	-84^L	-84^L	-78	-89^L	-74	-90^L
PRC 1764-B	D1	-85^L	-78^L	-81	-92^L	-79	-90^L
	D2	-86^L	-76^L	-79	-92^L	-76	-100^L
	D3	-83^L	-83^L	-83^L	-96^L	-80	-89^L
	D4	-81^L	-84^L	-84^L	-94^L	-77	-85^L
		1285 Hrs.					
None	B1	-65	-47				
None	B2	32	-17				
Chomerics 4375-27-4	B3	-66	-52				

Note - Entries with a "L" indicate that the reading was limited by the measurement sensitivity and that the transfer impedance was probably <u>lower</u> (i.e., more negative) than the entered value.

Table 5. Location of Test Areas on E-3 Aircraft and Conductive Sealants

Test Area	Type of Sealant
Entry Door, Forward	Products Research 1764 A/B
Entry Door, Aft	" " "
Air Vent EMP Shield in Rotodome	Chomerics 4375-27-4 A/B
Vertical Tail Fin	" "

Table 6. Corrosion Areas on E-3 Aircraft and Results of Inspections

Area on E-3	Results of Visual Inspections	
	Before Treatment Oct. 28, 1989	After Treatment Oct. 12, 1991
Entry Door, Forward	0.12 in. pits along surfaces	No additional pitting
Entry Door, Aft	0.12 in. pits along surfaces	No additional pitting
Air Vent EMP Shield in Rotodome	Severe corrosion in shield[1] (vent was partially destroyed)	No additional pitting
Vertical Tail Fin	0.03 in. pitting observed	No additional pitting

1 - The shield was replaced with nonconductive sealant after GTRI measured the dc resistance by OC-ALC, probably because the center of the shield was severely corroded.

Table 7. Results of DC Resistance and Transfer Impedance Measurements on E-3 Aircraft

Area on E-3	dc Resistance milliohms Untreated/Treated	Transfer Impedance milliohms Untreated/Treated	dc Resistance milliohms 24 months	Transfer Impedance milliohms 24 months
Entry Door, Forward (Products Research 1764)	0.62-11.1/ 0.23-0.37	Not tested	0.49-0.62	Not tested
Entry Door, Aft (Products Research 1764)	1.20-1.28/ 0.48-0.50	Not tested	1.4-4.6	Not tested
Air Vent EMP Shield in Rotodome (Chromerics 4375-27-4)	1.45-5.50/ 0.10-0.10	Not tested	1.4-11.3[1]	Not tested
Vertical Tail Fin (Chomerics 4375-27-4)	0.40-0.40/ 0.39-0.39	(A)3.20-1000/ 0.32-56.00	0.20-1.9	(A) 4.63-89
		(B)1.80-0.32/ 0.40-56.00		(B) 0.16-119
		(C)2.50-0.45/ 0.10-1000		(C)0.16-1000

1 - After dc measurements, the shield was removed and replaced by OC-ALC without GTRI sealant, which caused the resistance to increase, and eliminated the experiment.
Note: A, B and C are three different test locations on fin (see Figure 4).

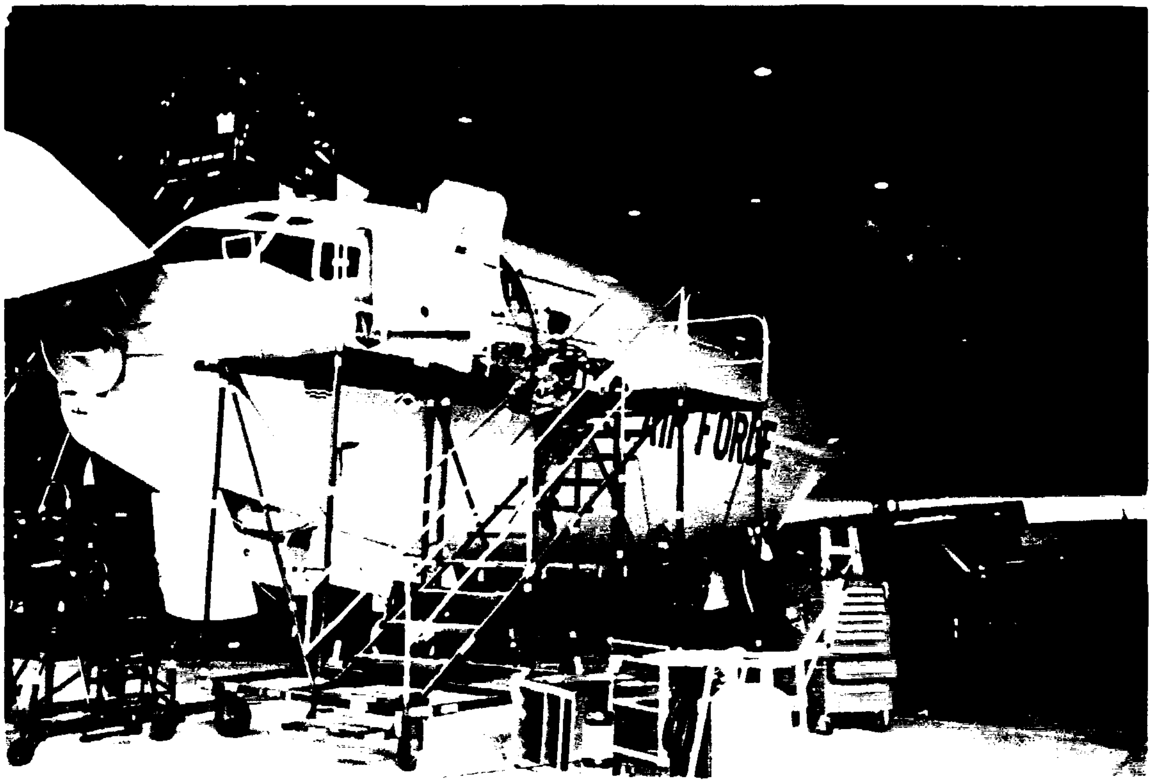


Figure 8. Front-left view of E-3 aircraft showing forward and aft entry doors.

Figure 9. View of forward door, bottom view of sealing gasket and corrosion areas.

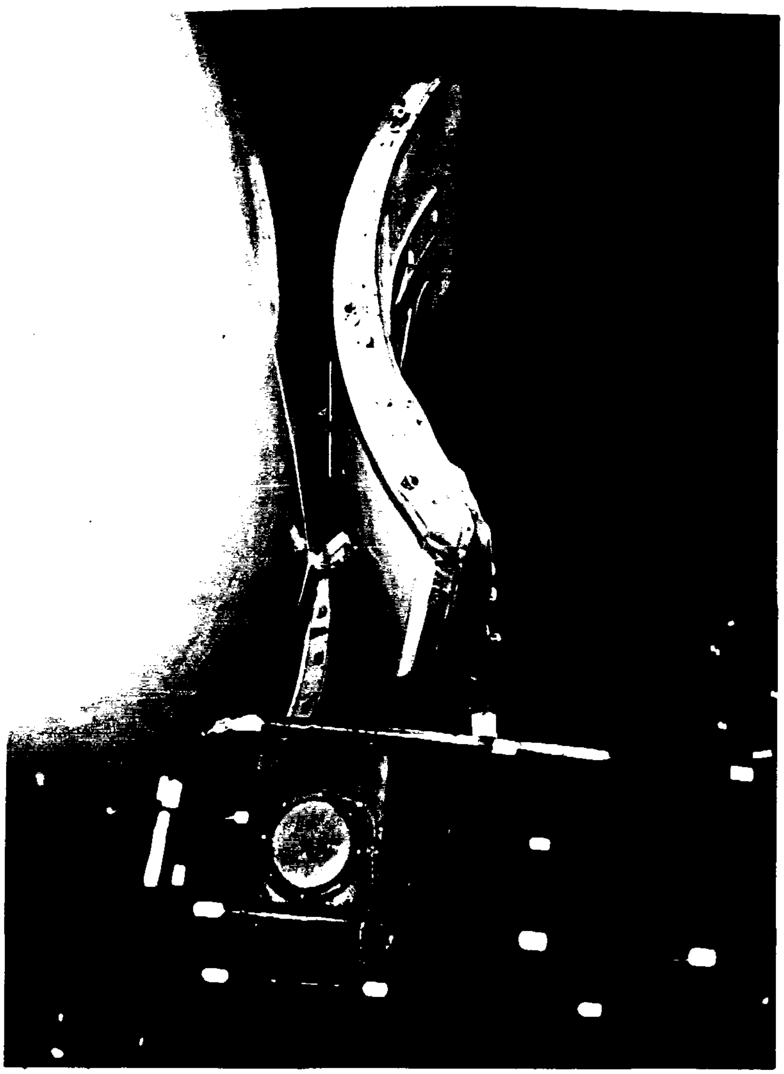


Figure 10. View of the bottom section of the forward entry door and corrosion areas.

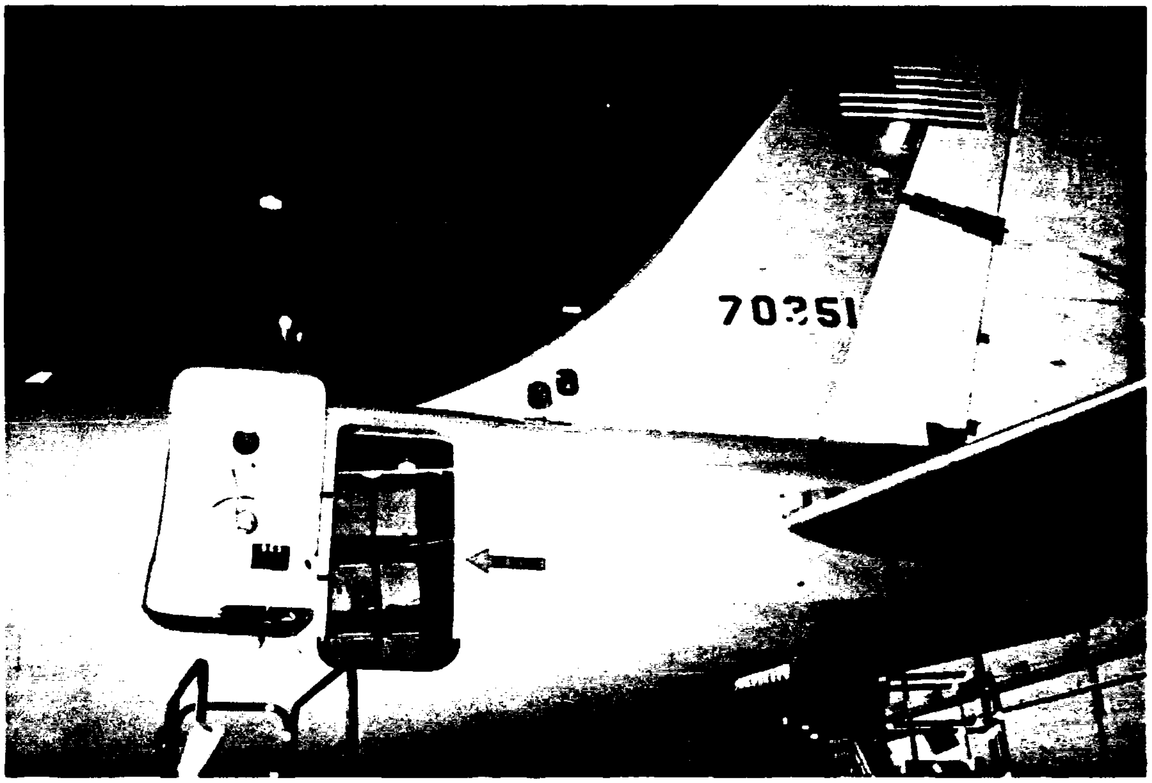


Figure 11. View of open aft entry door.

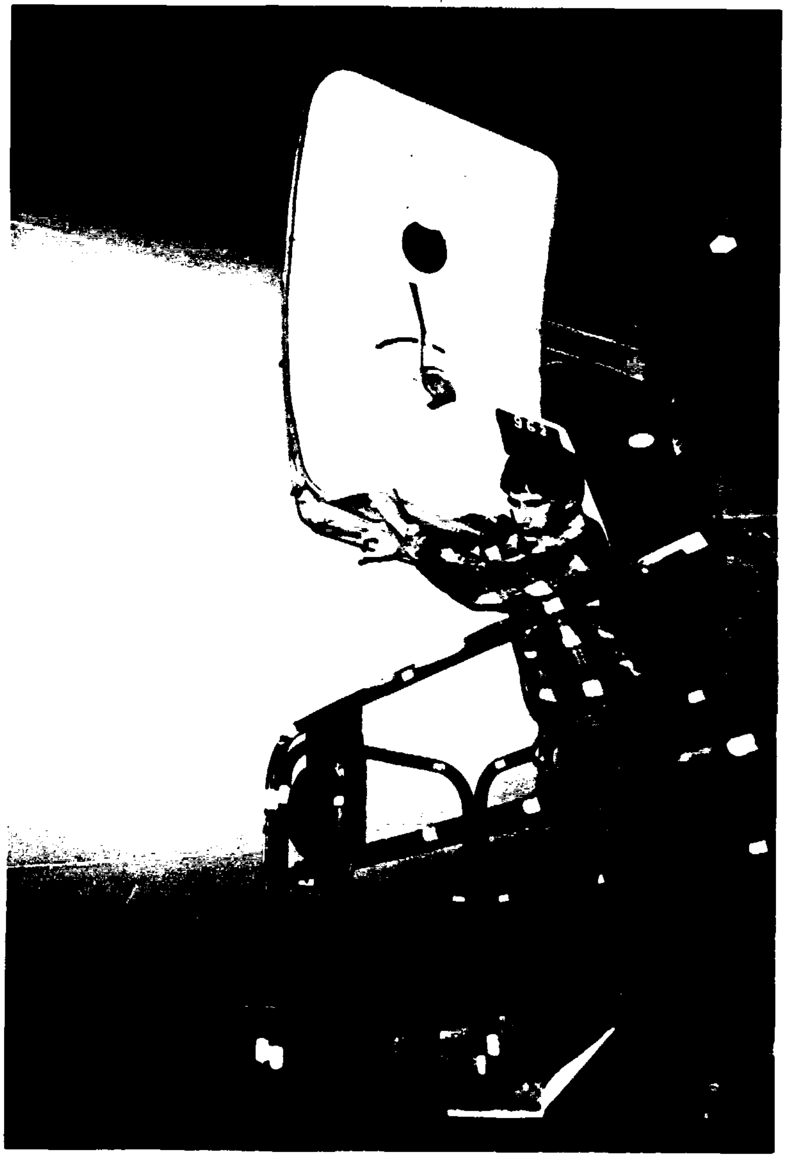


Figure 12. View of bottom section of the aft entry door and corrosion.

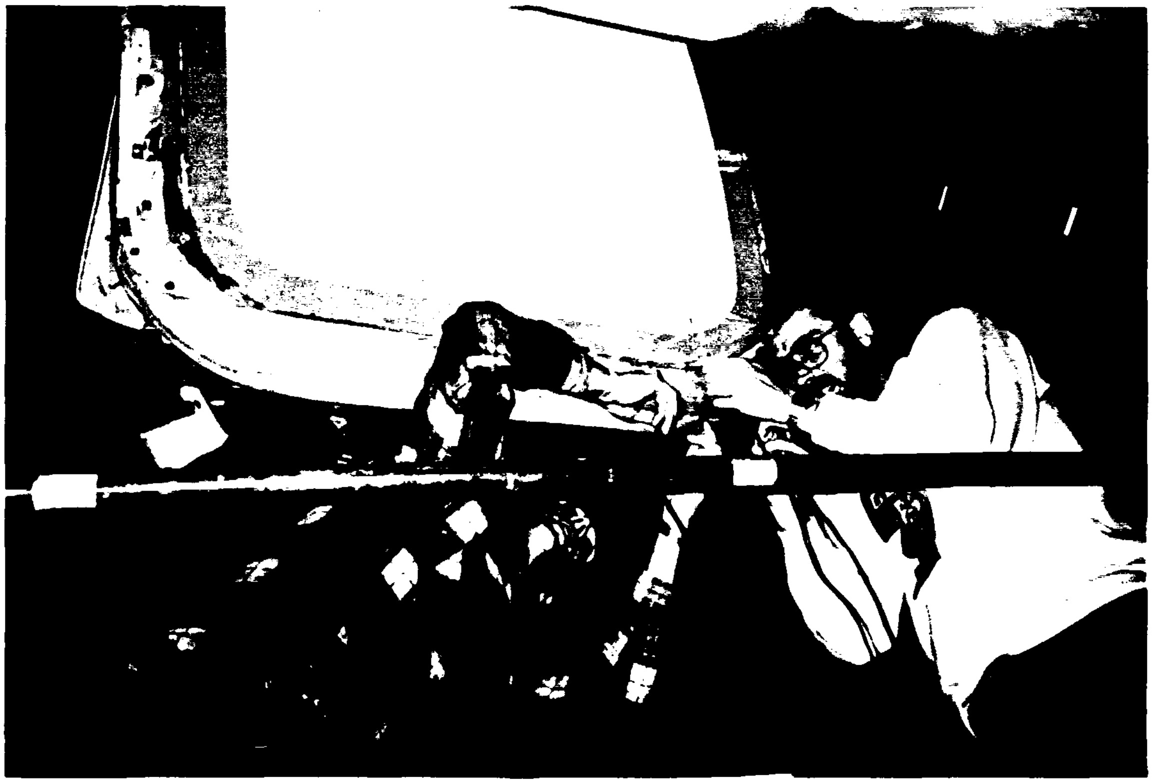


Figure 13. Installation of probes for measurement of dc resistance on bottom section of forward entry door.

Figure 14. Forward - right view of E-3 aircraft showing the vertical tail fin panel.

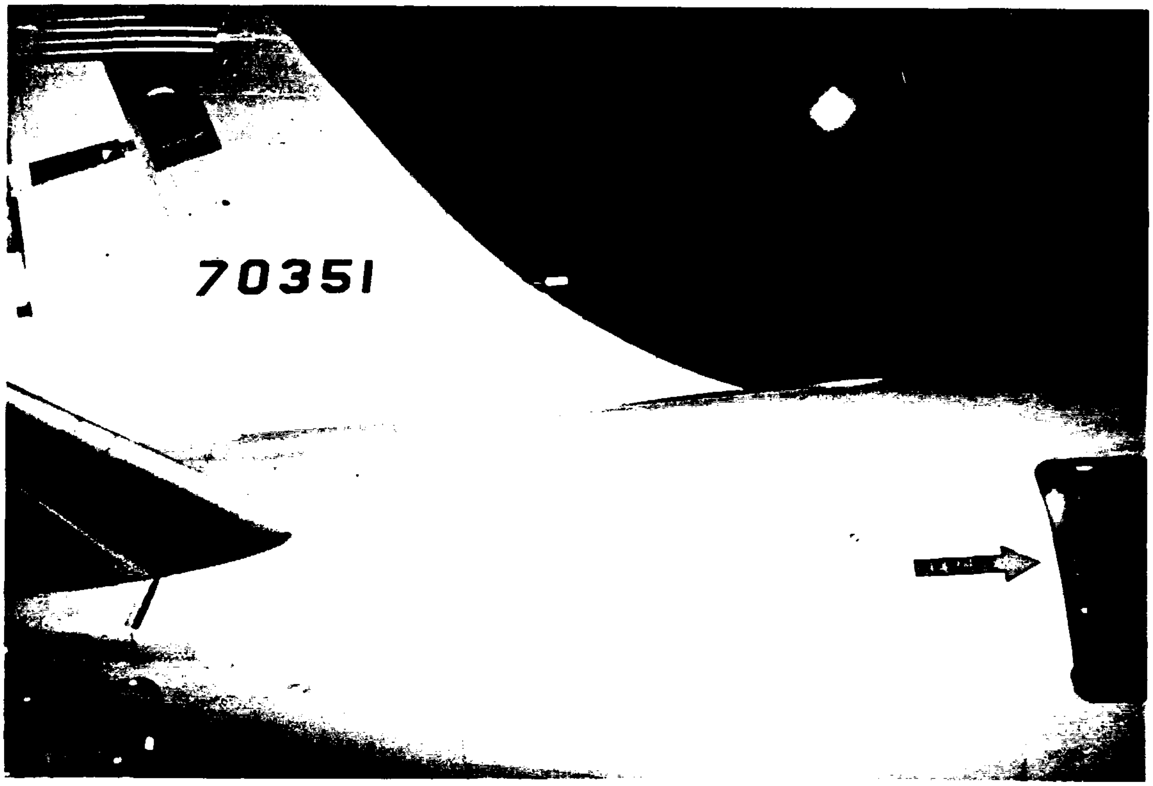


Figure 15. View of the tail section of the E-3A aircraft showing vertical tail fin panel and corrosion area.

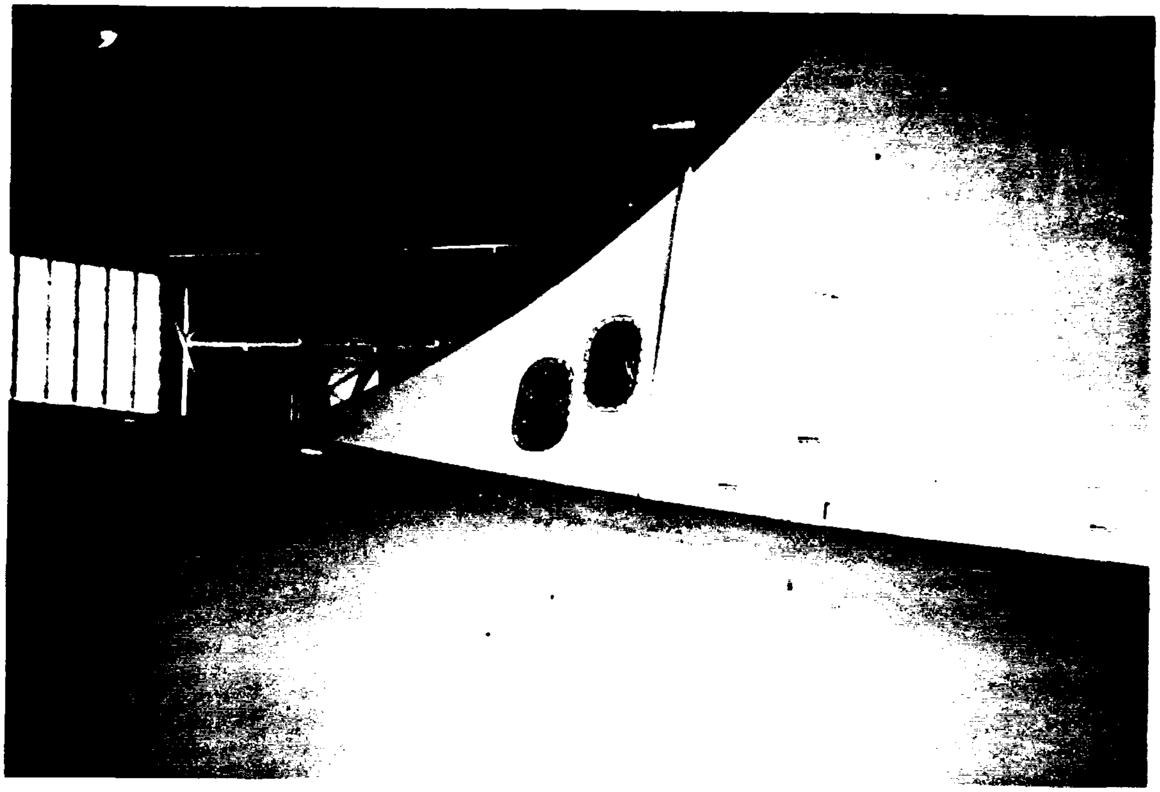


Figure 16. View of the tail section, left side, showing the access panel for measuring transfer impedance.

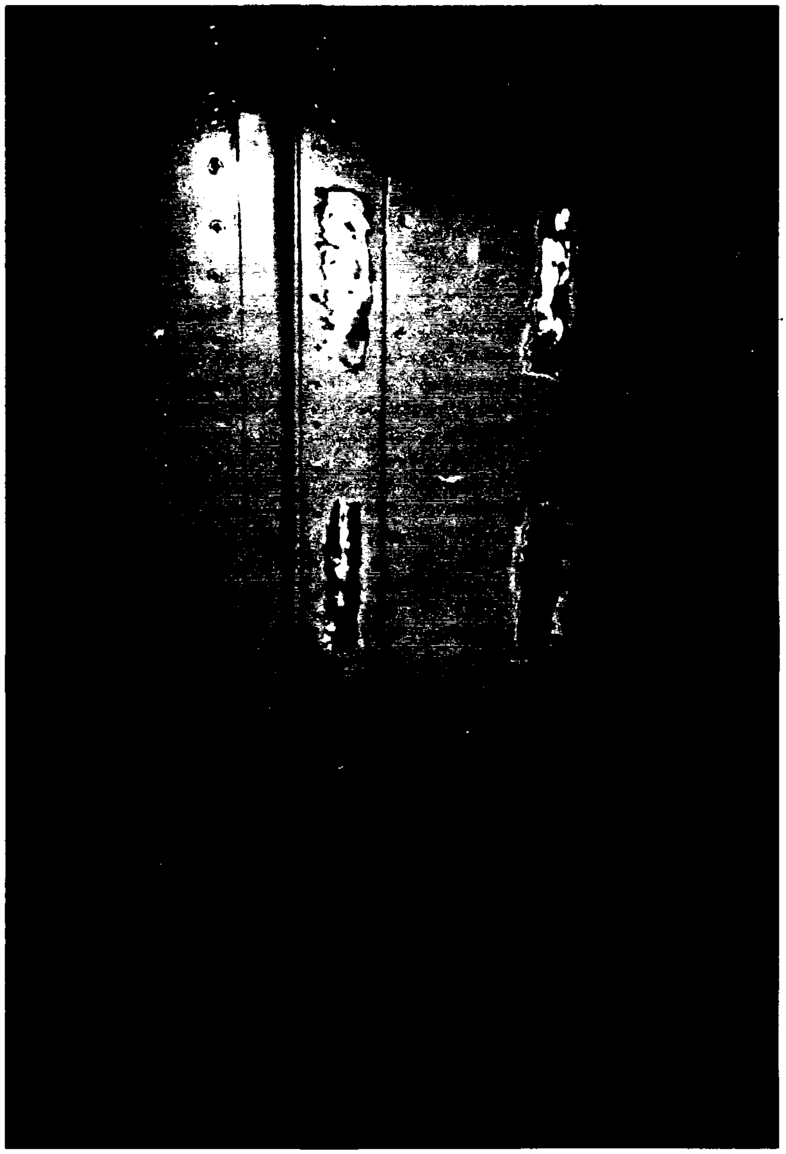


Figure 17. Preparation of vertical tail fin panel, removal of paint to bare metal, for attachment of transfer impedance fixture.

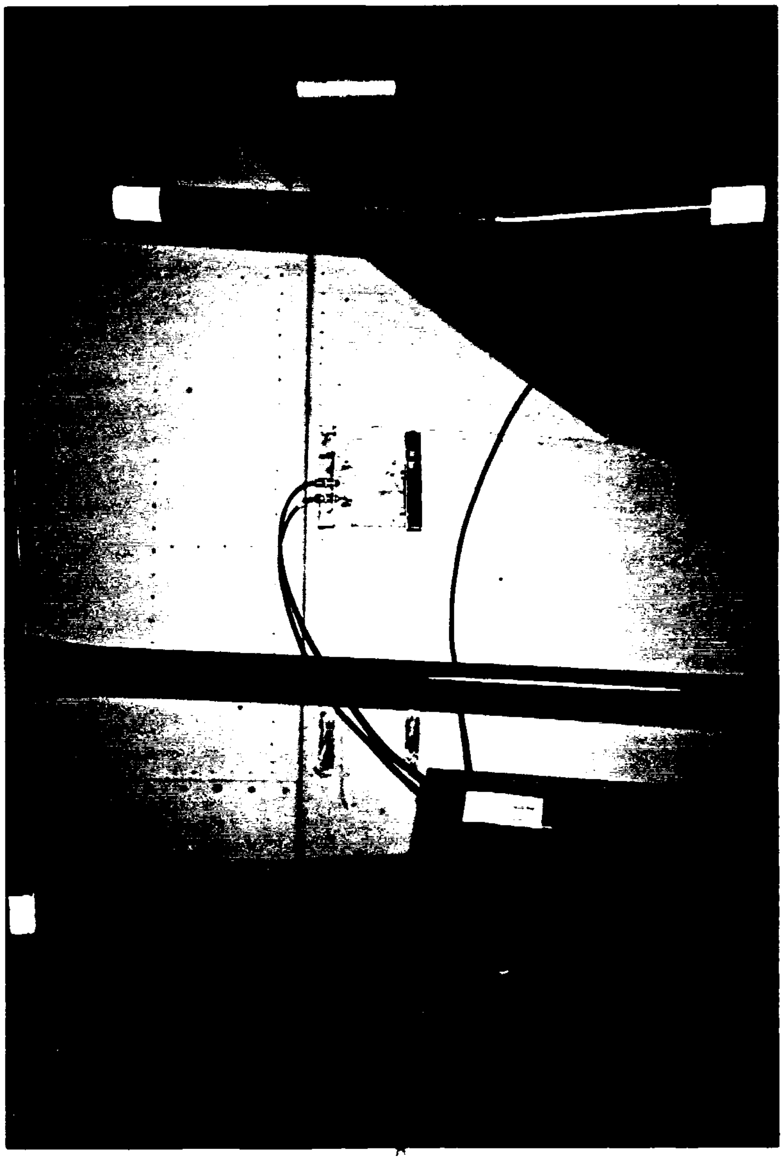


Figure 18. Installation of transfer impedance fixture.

Figure 19. View of fixture and instruments for measuring transfer impedance.

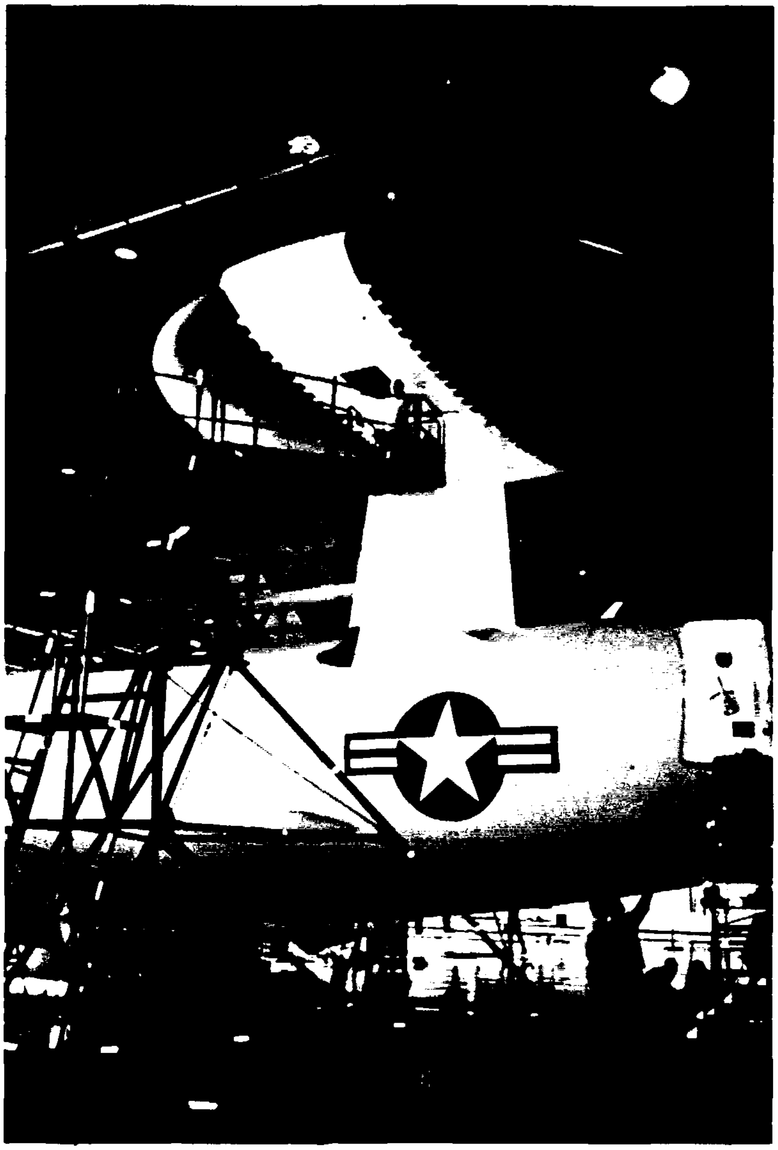


Figure 20. Ground view of bottom side of rotodome and entry door.

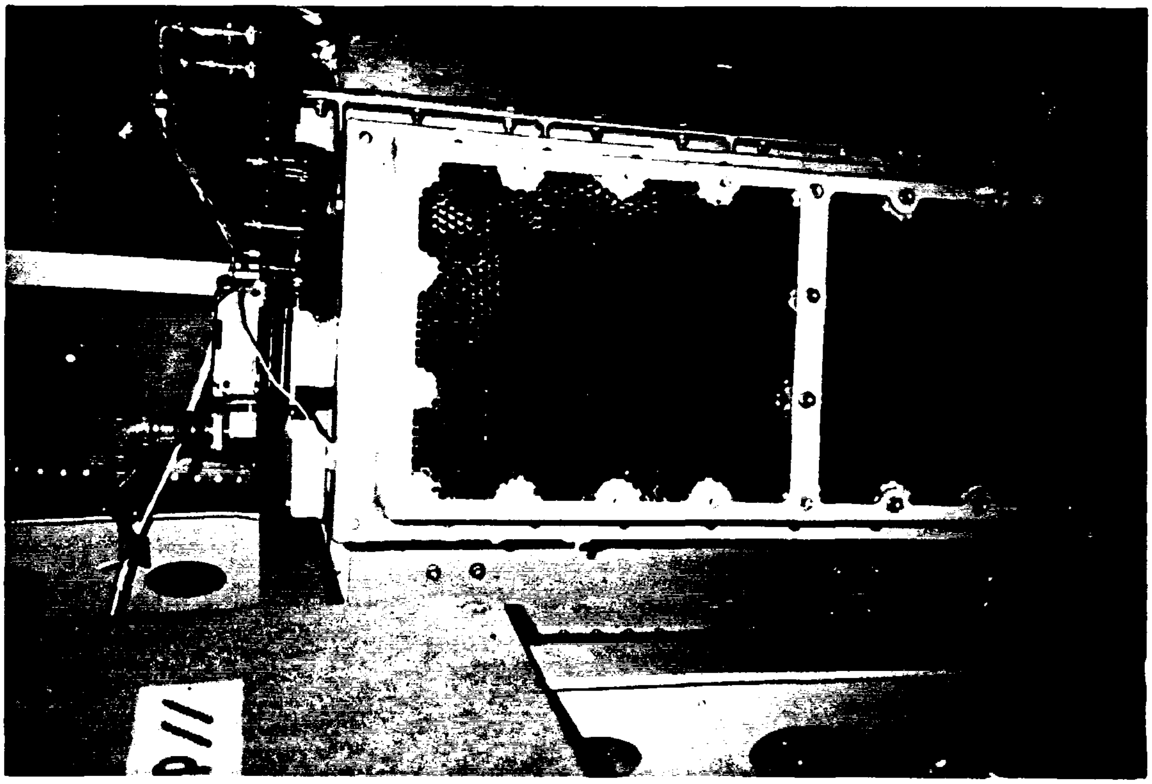
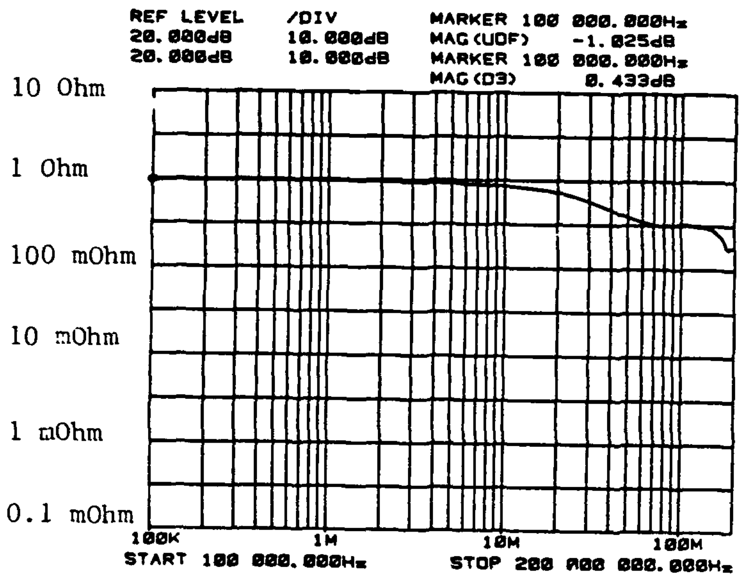


Figure 21. Front view of air inlet duct EMP shield.

(a) Lab Test Fixture Results



(b) Field Test Fixture Results

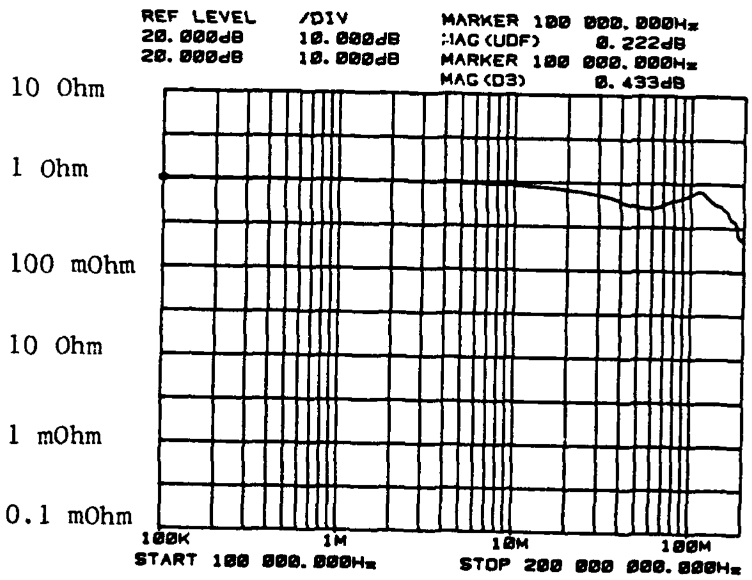
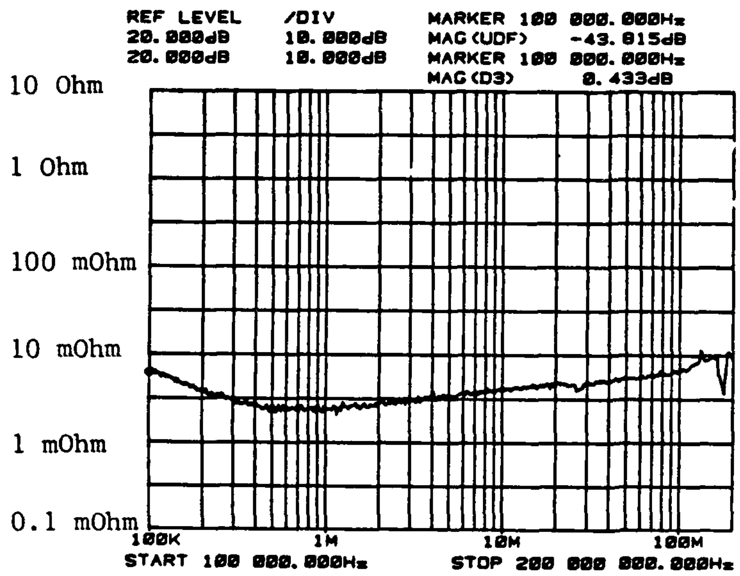


Figure 22. Comparison of Measured Z_t Using Lab and Field Test Fixtures (R_{dc} = 1 Ohm)

(a) Lab Test Fixture Results



(b) Field Test Fixture Results

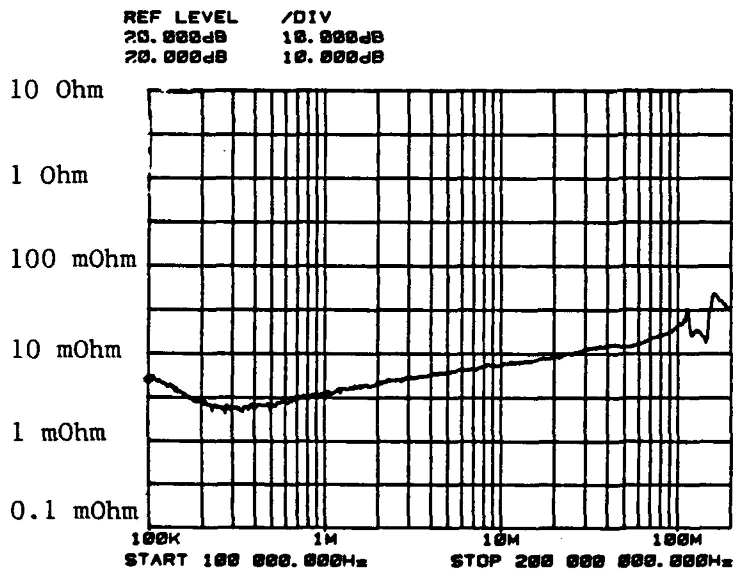
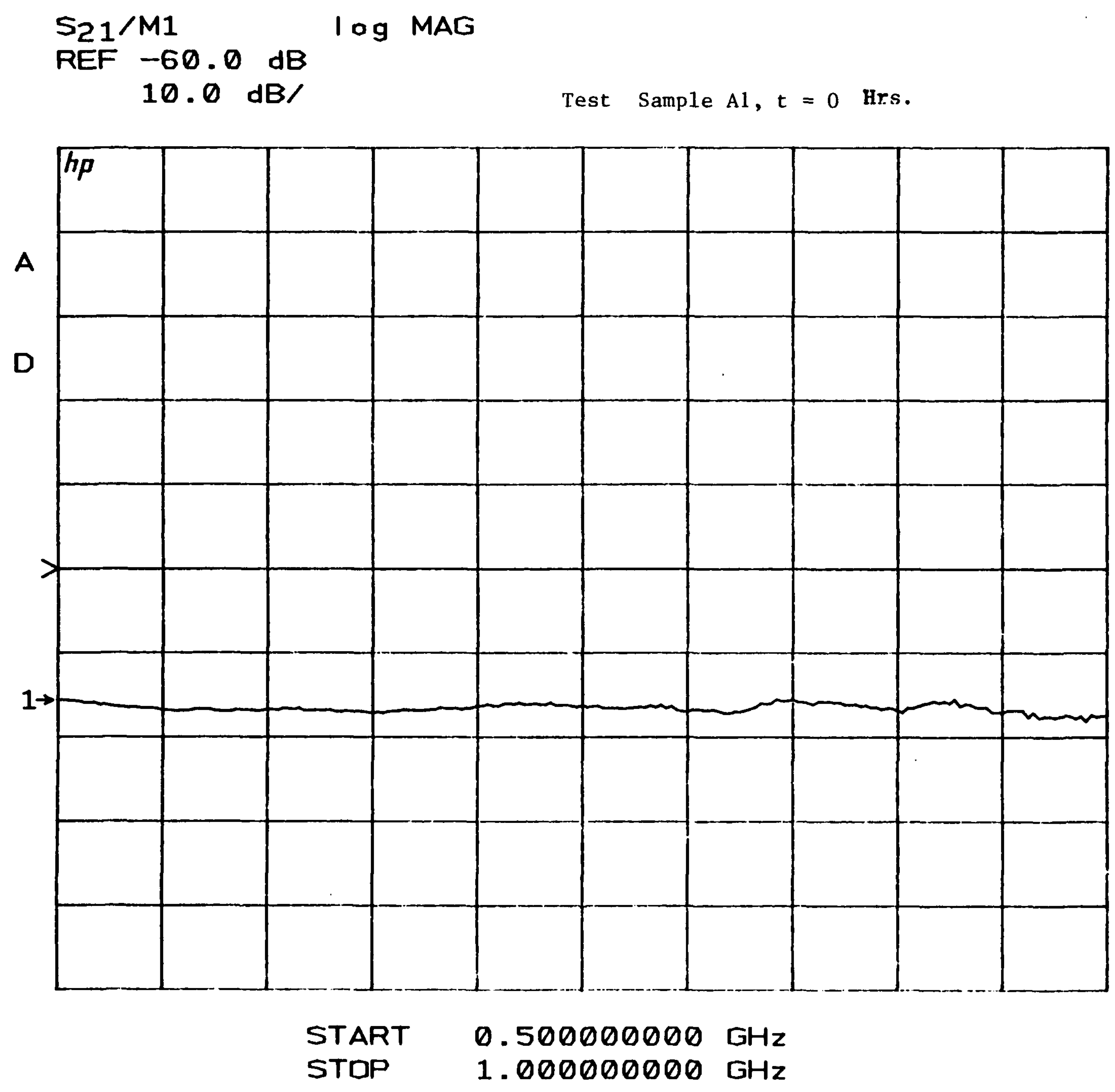
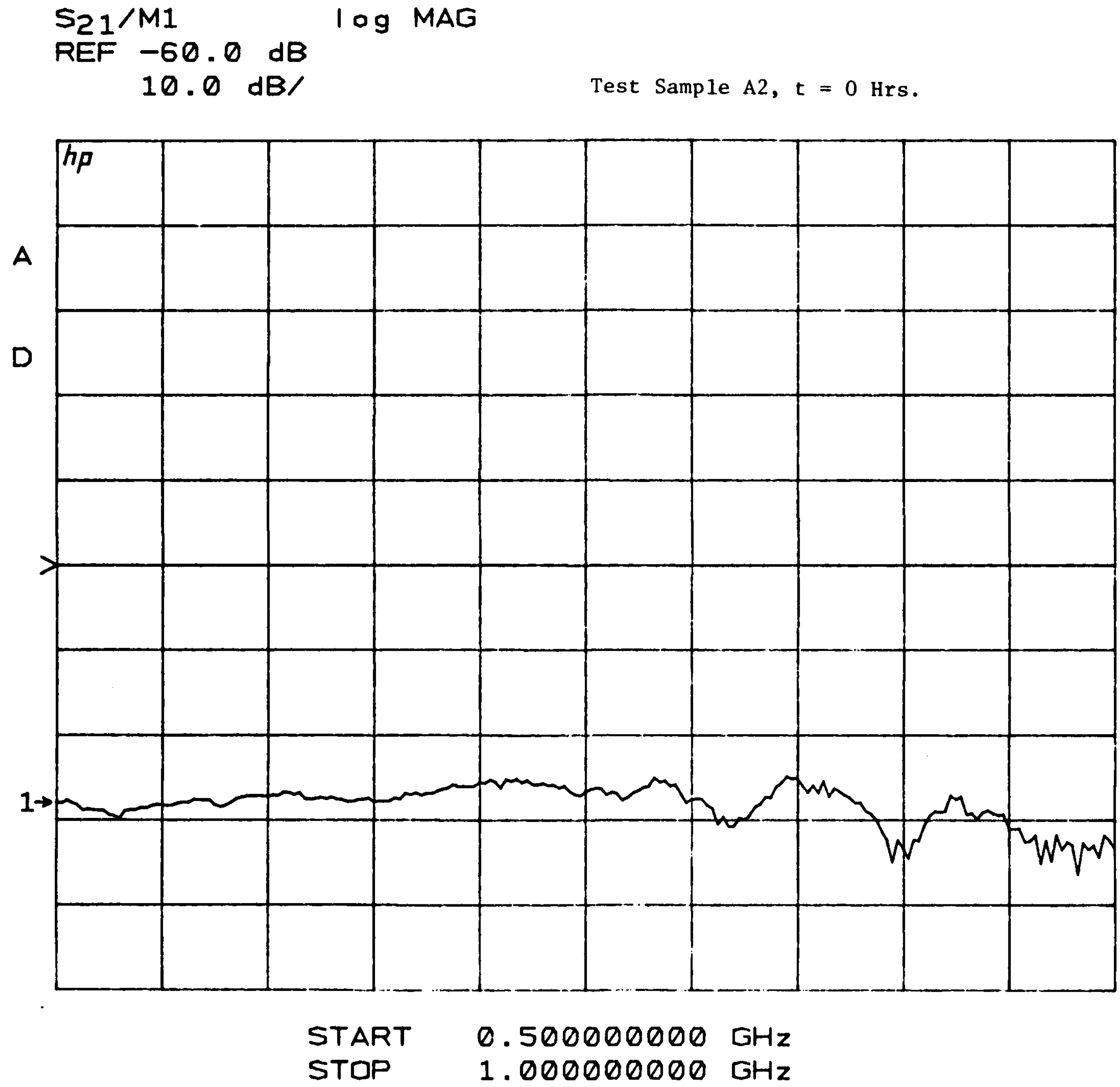


Figure 23. Comparison of Measured Z_t Using Lab and Field Test Fixtures (R_{dc} = 5 milliohm)

APPENDIX A

SHIELDING EFFECTIVENESS DATA

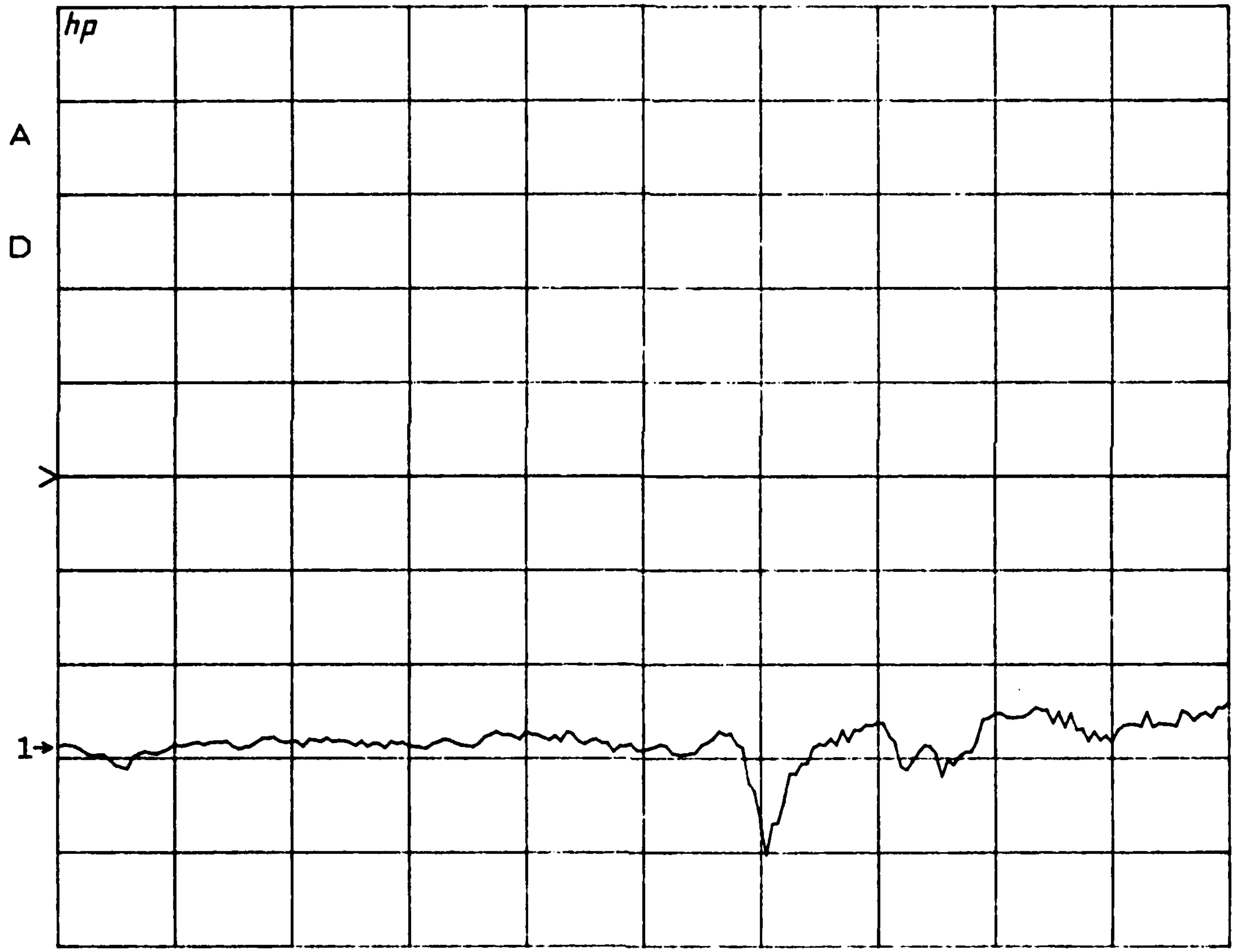

S21/M1 log MAG
REF -60.0 dB
10.0 dB/
Test Sample A1, t = 0 Hrs.
hp
A
D
1
START 0.500000000 GHz
STOP 1.000000000 GHz



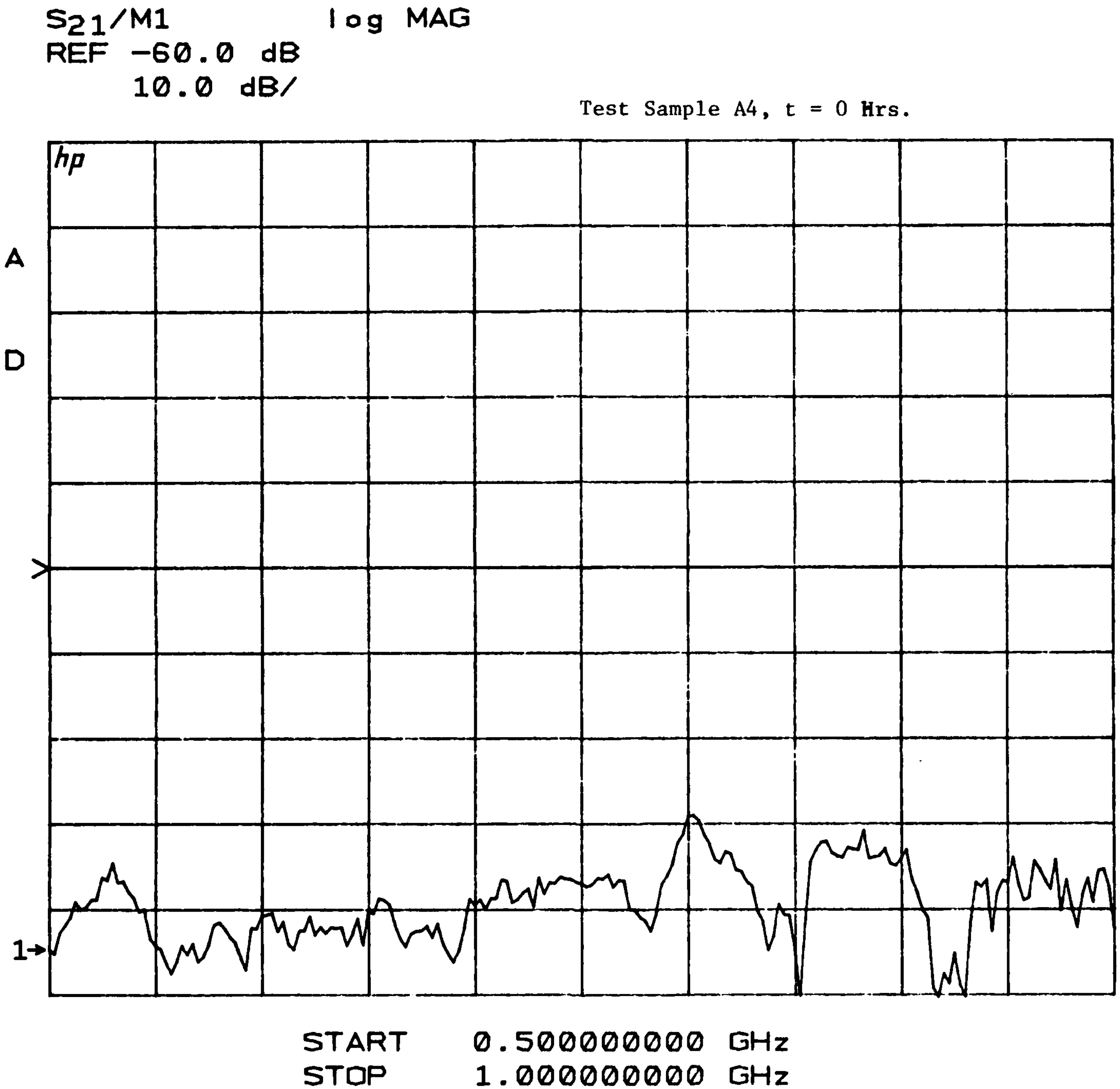
Test Sample A2, t = 0 Hrs.

S21/M1 log MAG
REF -60.0 dB
10.0 dB/

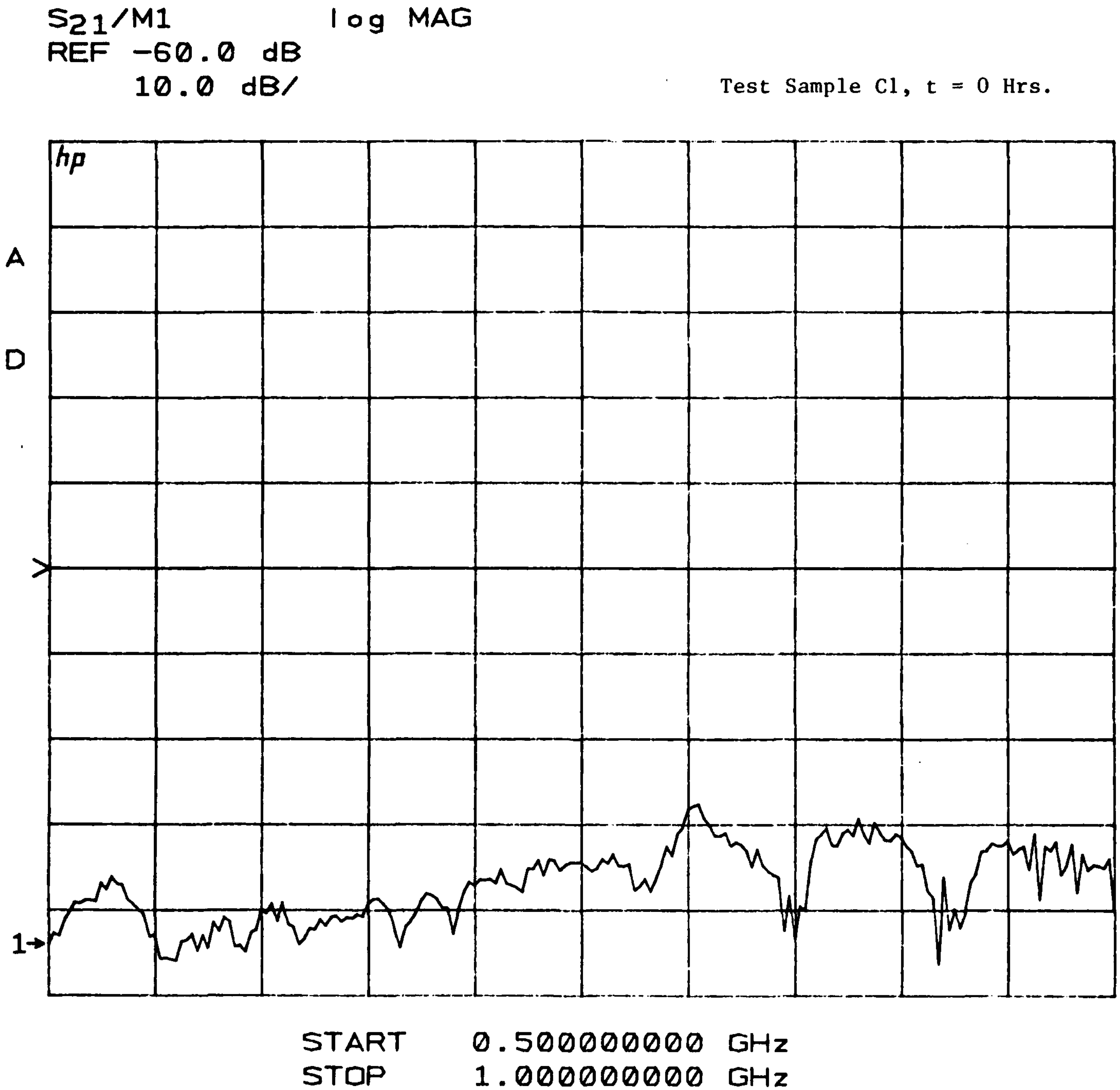
Test Sample A3, t = 0 Hrs.



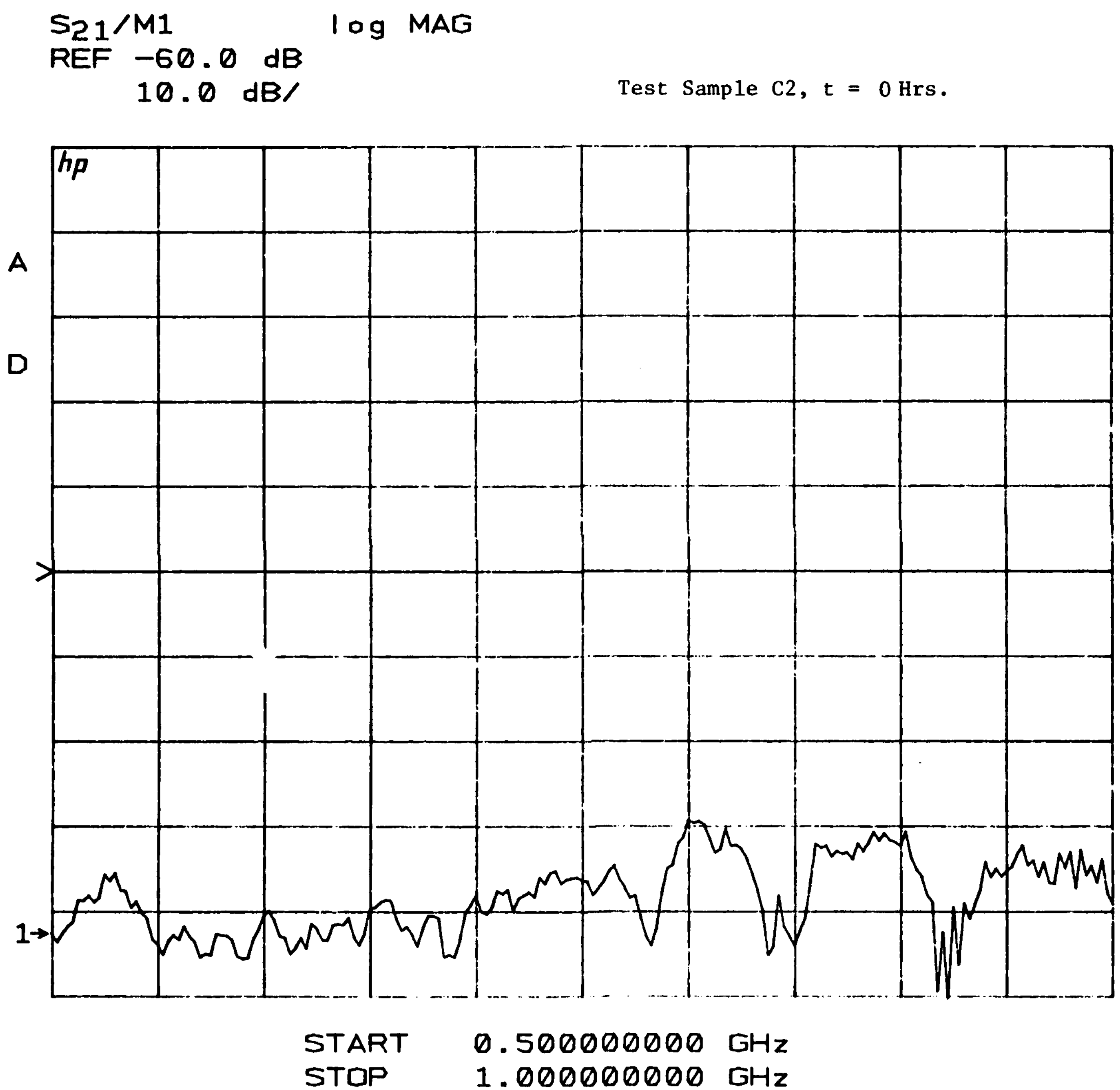
START 0.500000000 GHz
STOP 1.000000000 GHz



Test Sample A4, t = 0 Hrs.

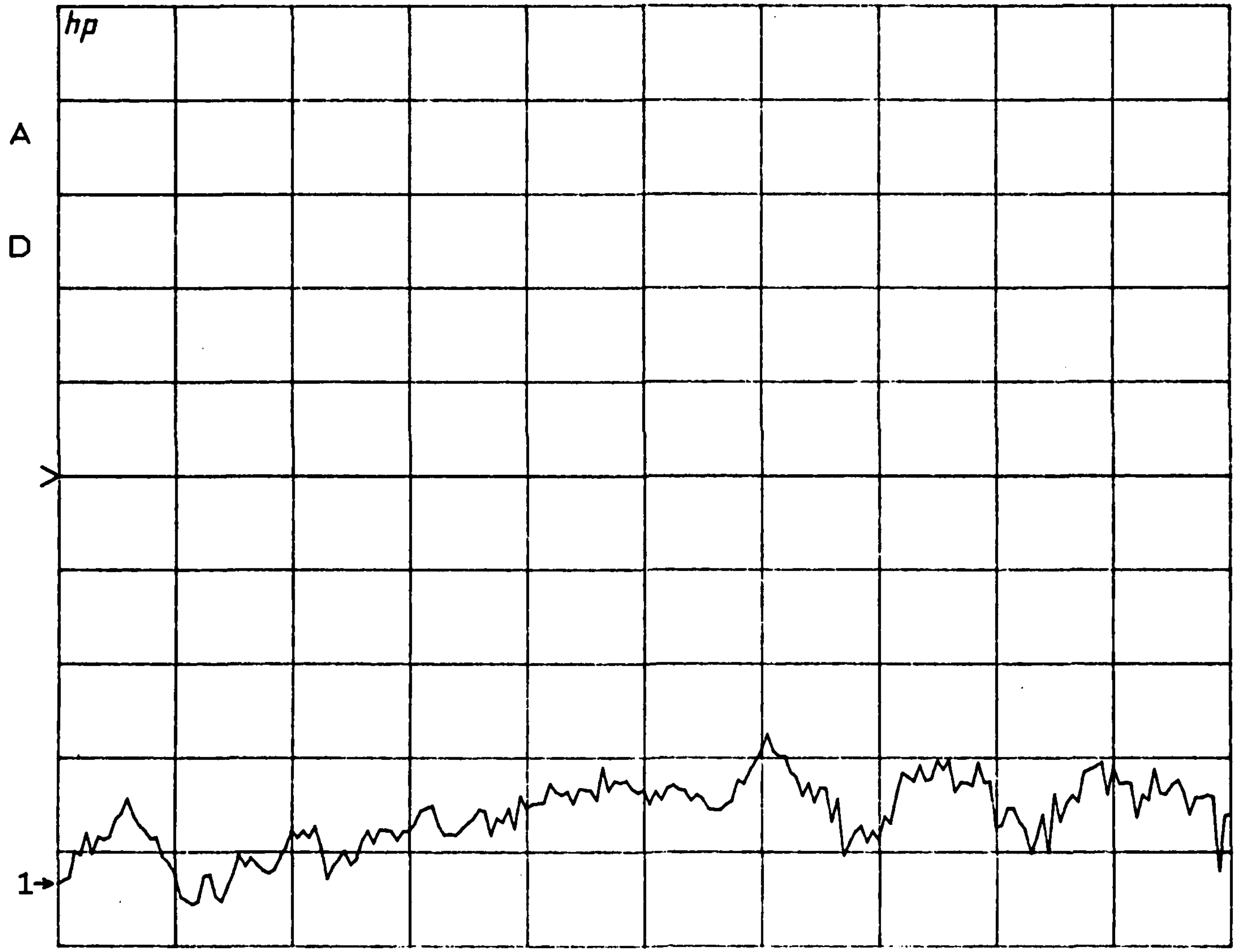

S21/M1
log MAG
REF -60.0 dB
10.0 dB/
Test Sample Cl, t = 0 Hrs.
hp
A
D
1
START 0.500000000 GHz
STOP 1.000000000 GHz

Test Sample C2, t = 0 Hrs.



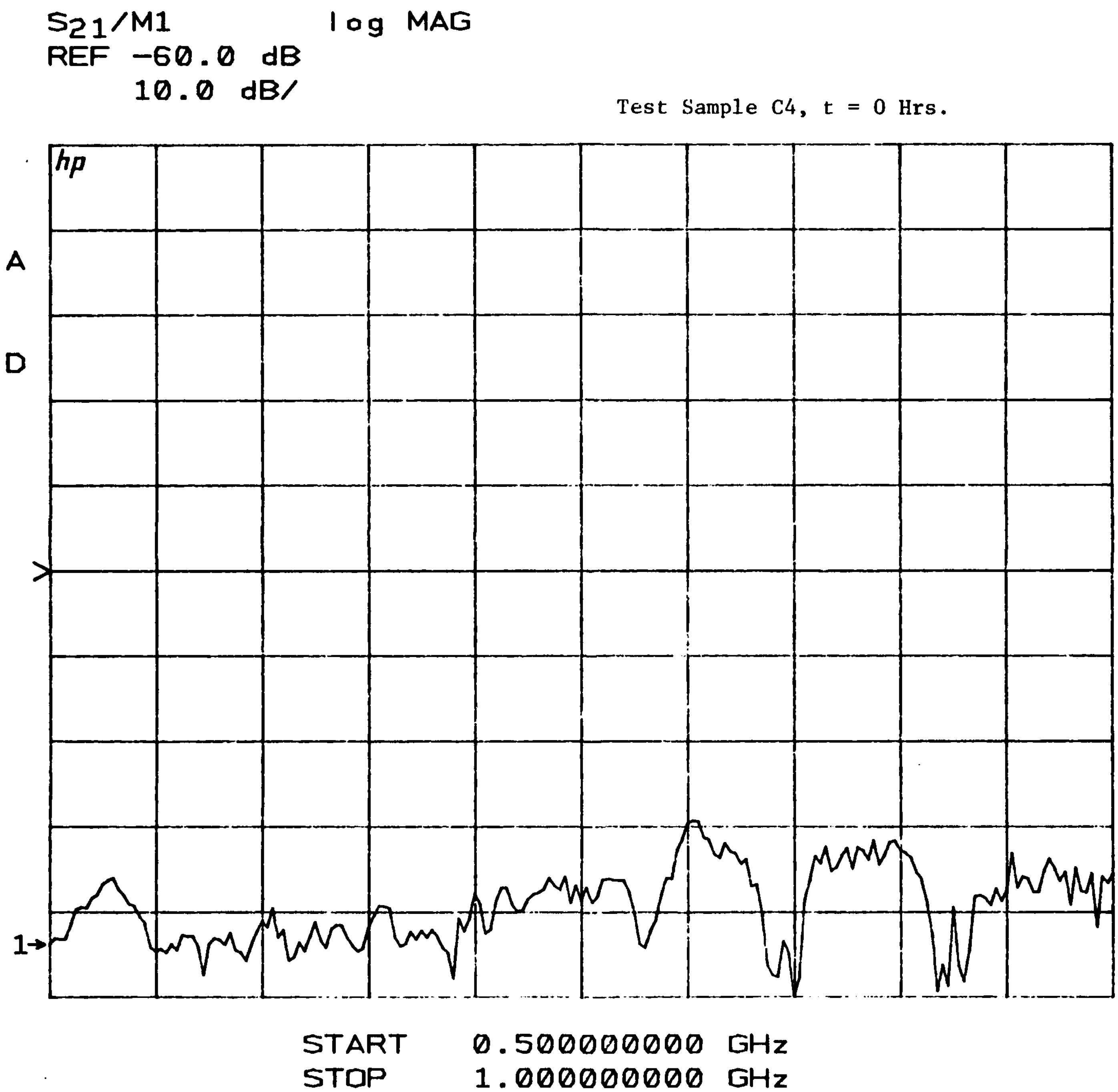
S_{21}/M1 log MAG
REF −60.0 dB
10.0 dB/

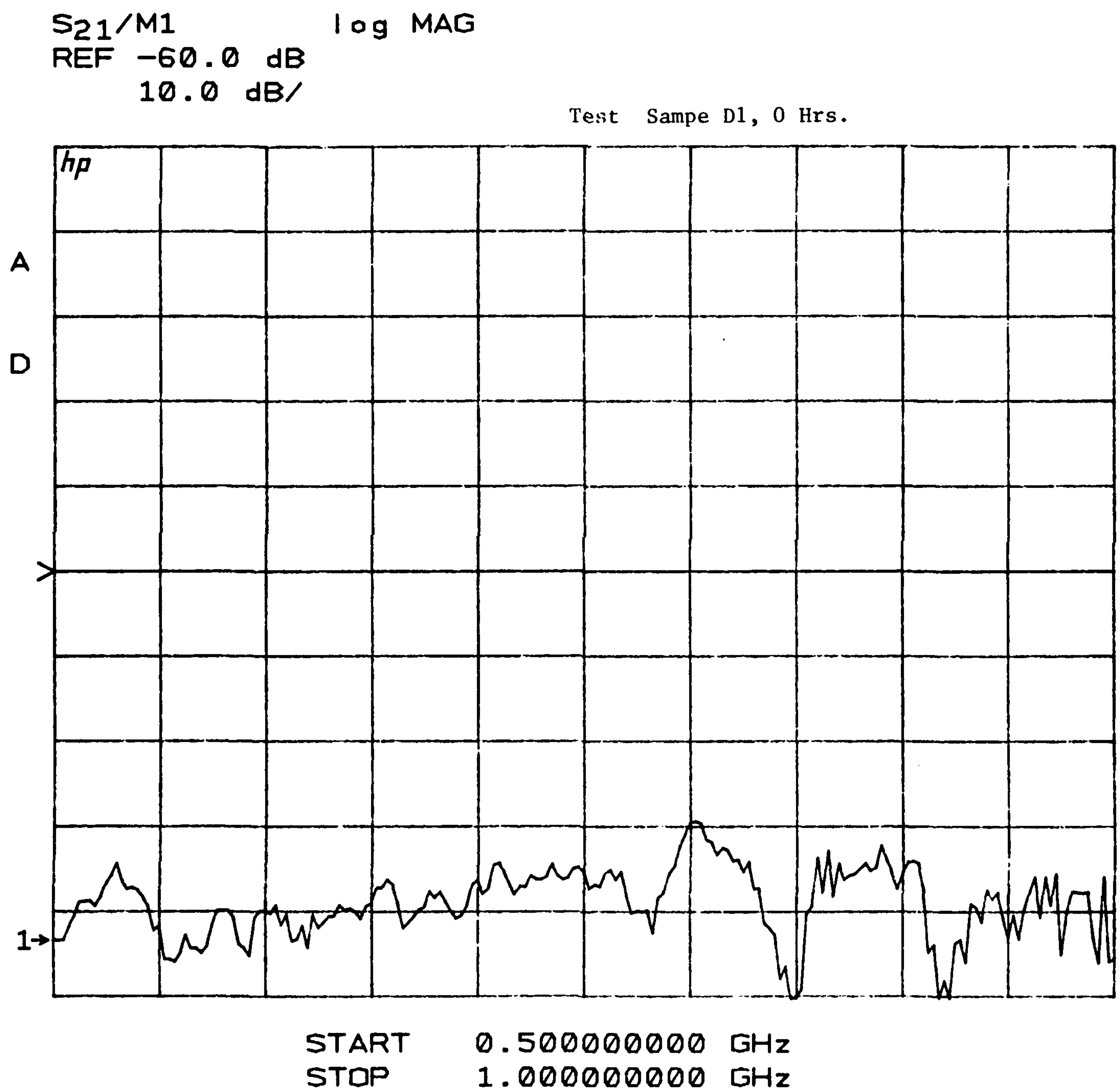
Test Sample C3, t = 0 Hrs.



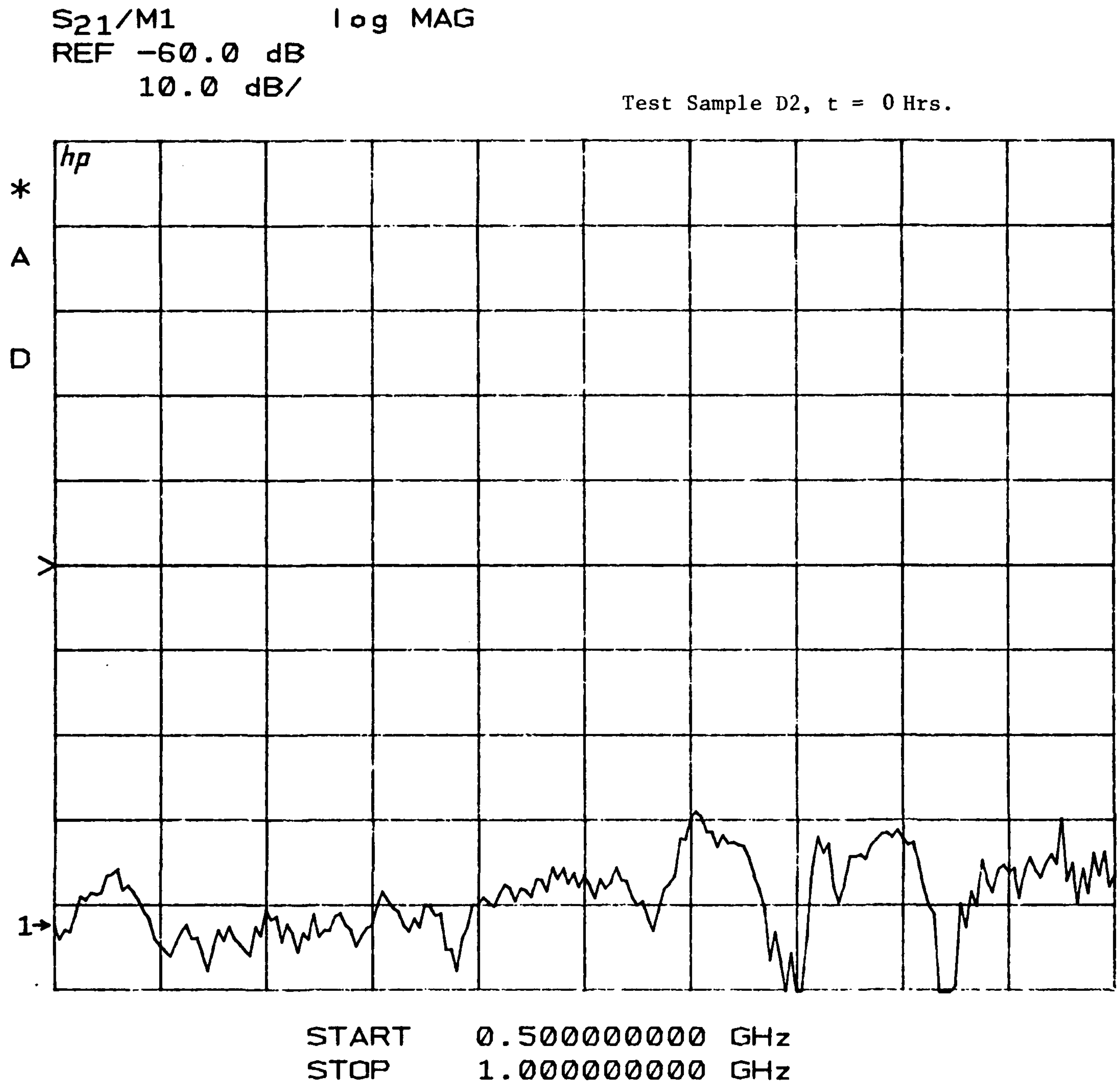
START 0.500000000 GHz
STOP 1.000000000 GHz

Test Sample C4, t = 0 Hrs.





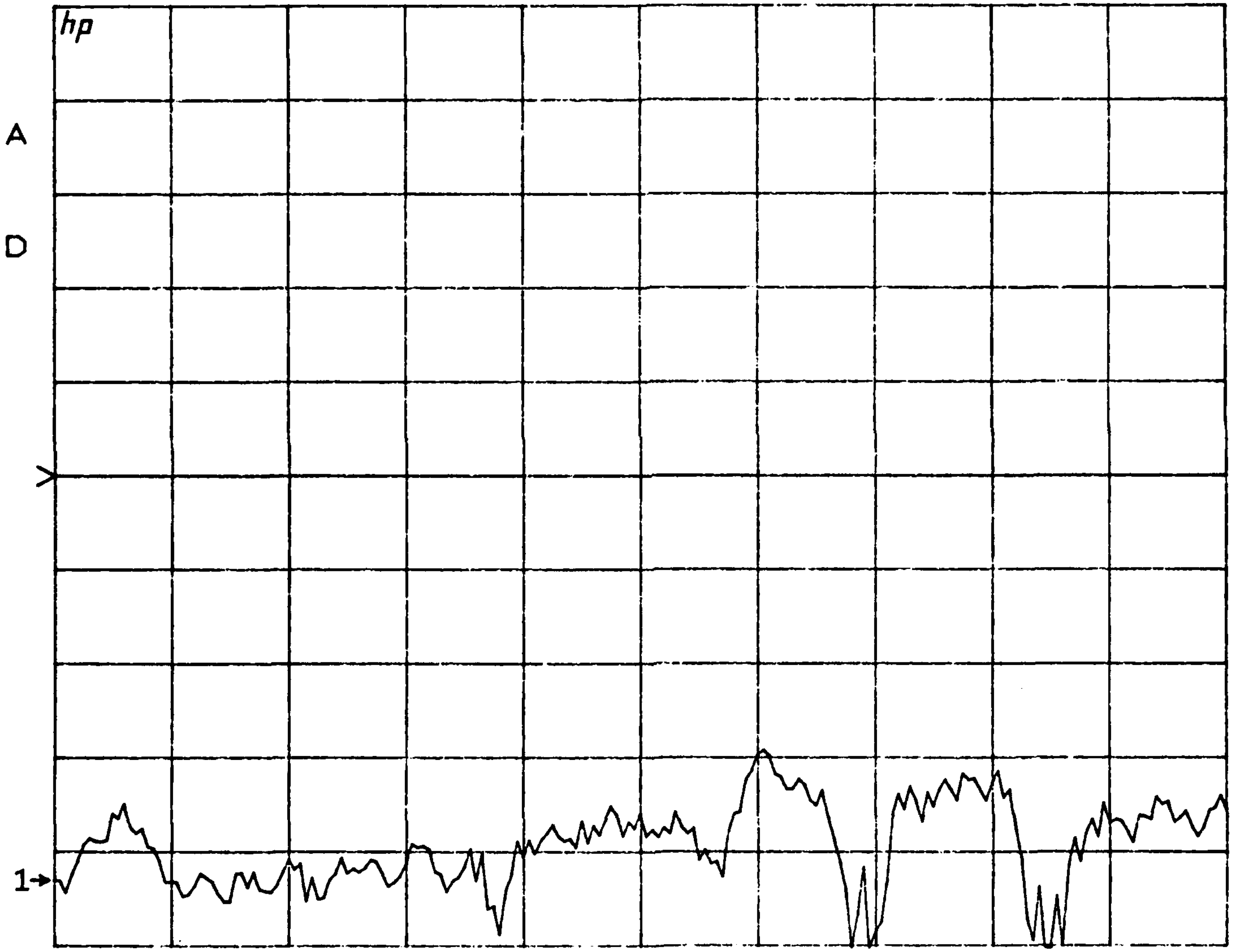
S_{21}/M1 log MAG
REF -60.0 dB
10.0 dB/
Test Sampe D1, 0 Hrs.
hp
A
D
1→
START 0.500000000 GHz
STOP 1.000000000 GHz



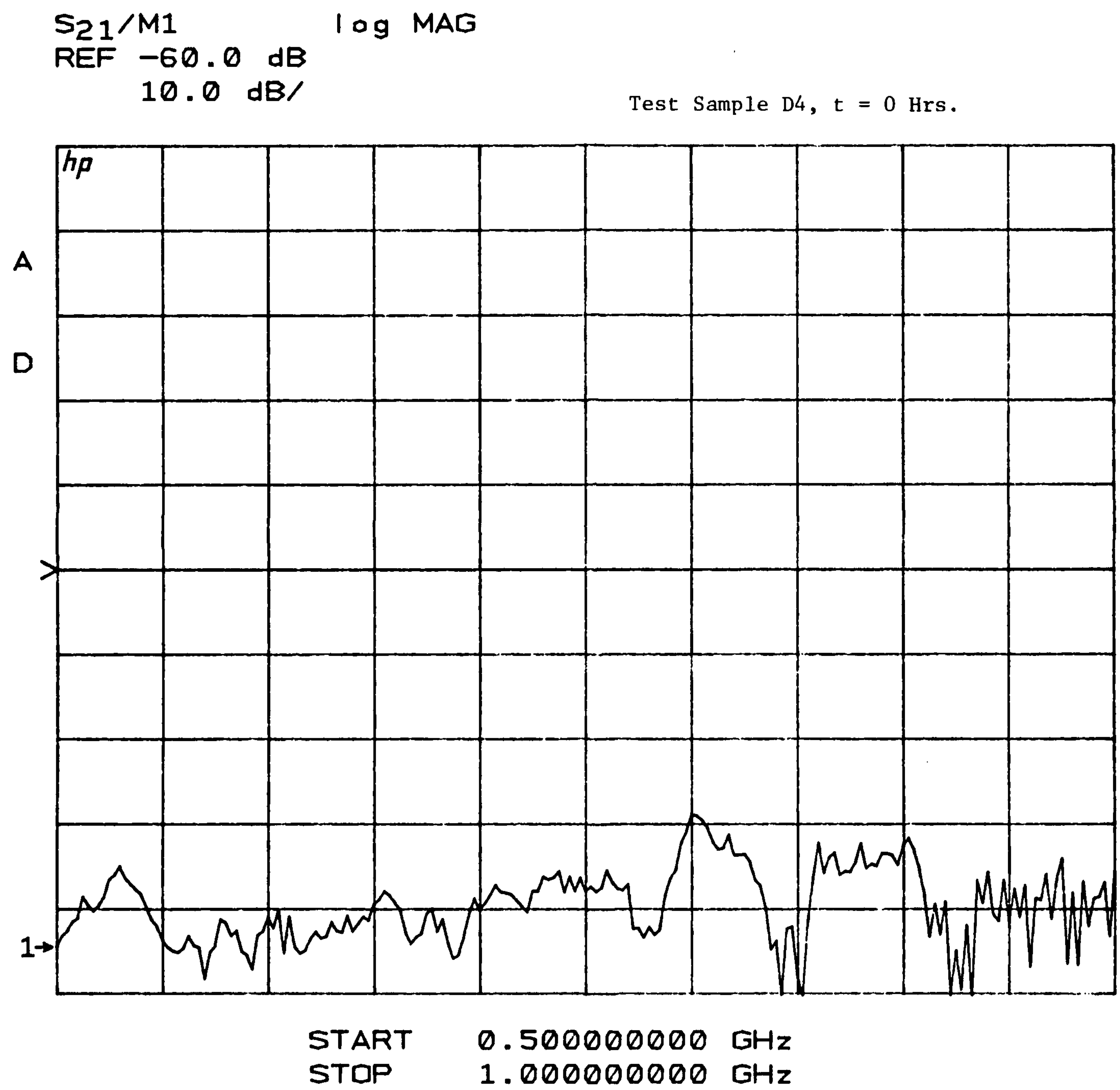
S21/M1
log MAG
REF -60.0 dB
10.0 dB/
Test Sample D2, t = 0 Hrs.
hp
*
A
D
1→
START 0.500000000 GHz
STOP 1.000000000 GHz

S_{21}/M1 log MAG
REF -60.0 dB
10.0 dB/

Test Sample D3, t = 0 Hrs.

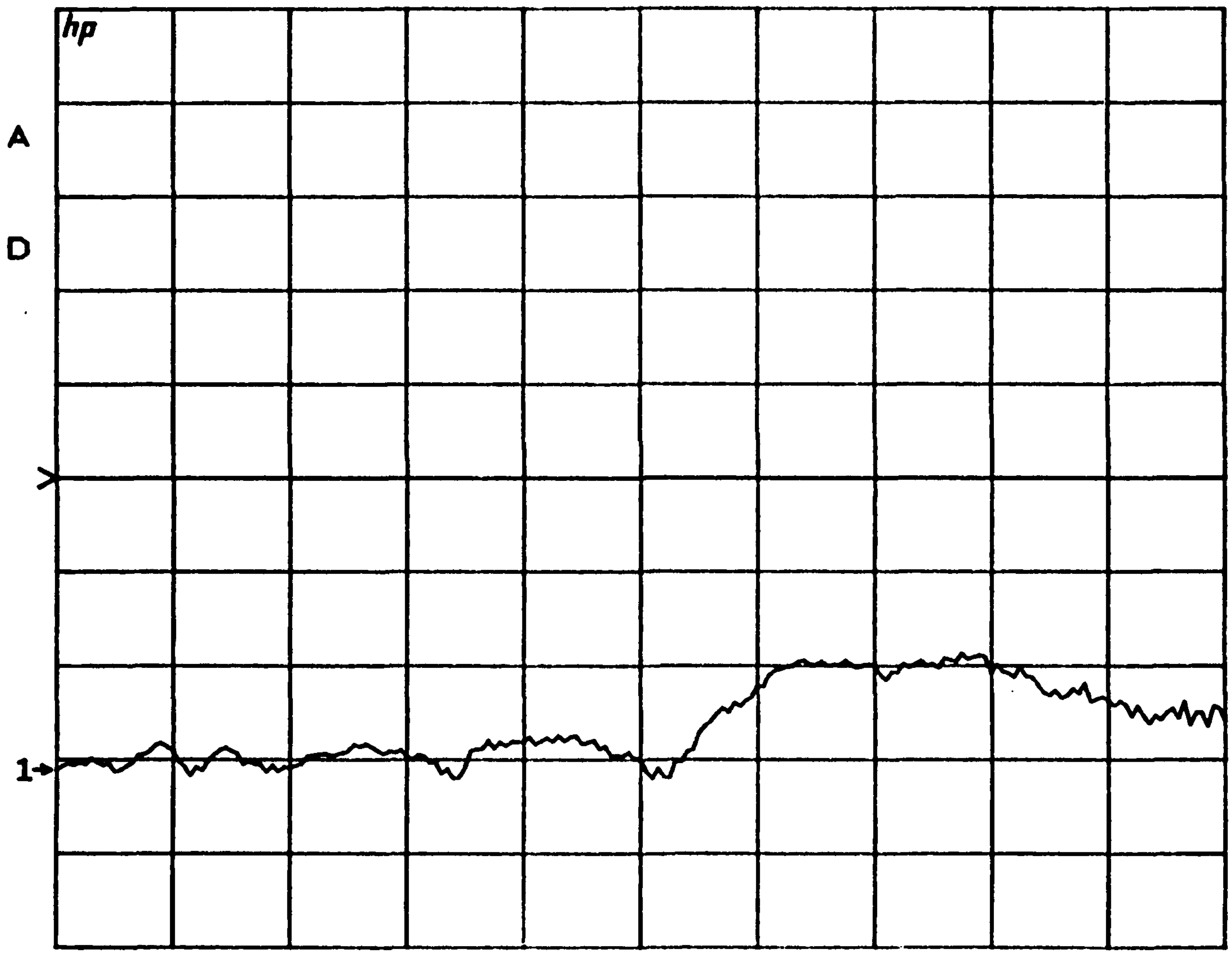


START 0.500000000 GHz
STOP 1.000000000 GHz

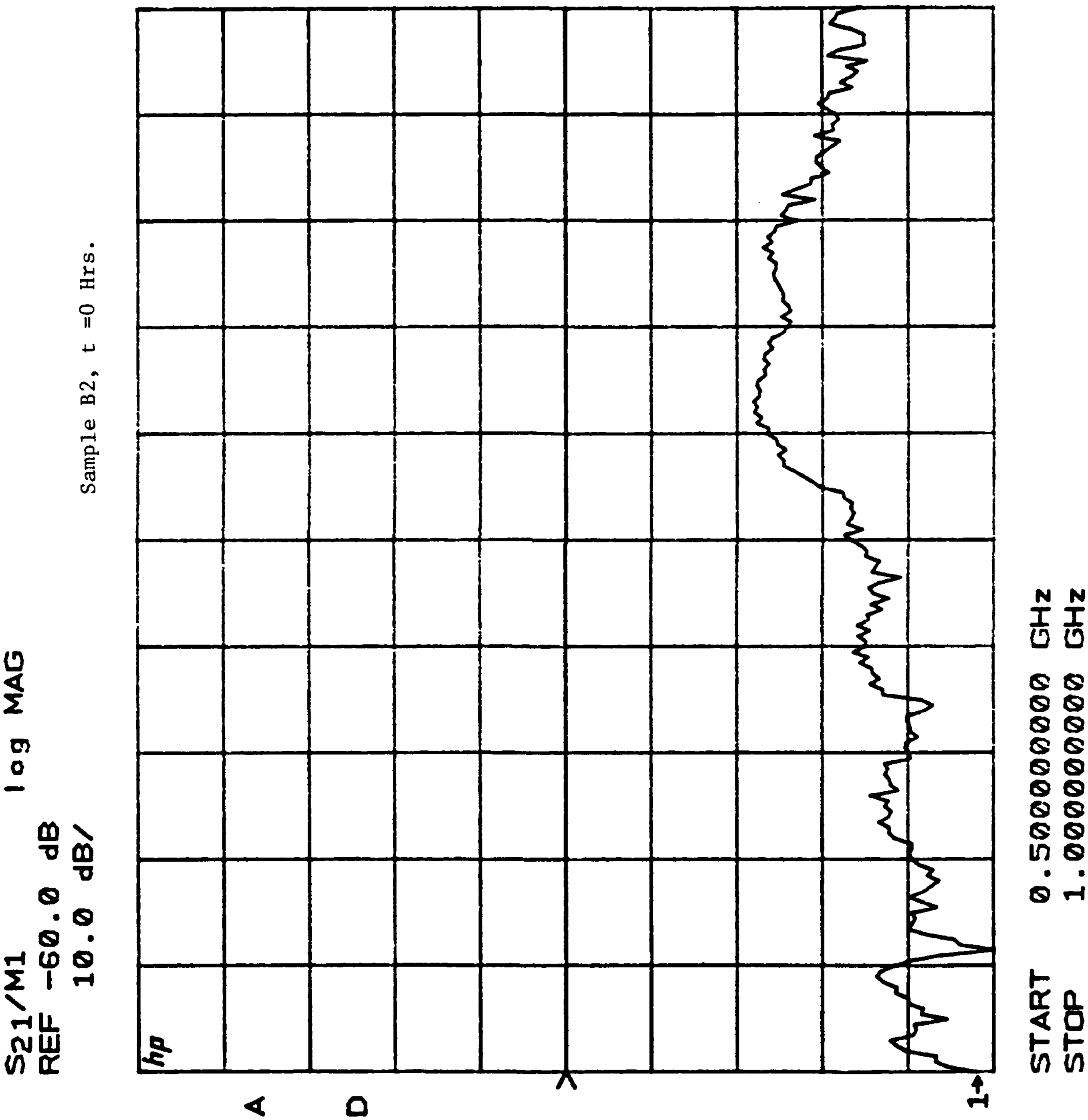

S21/M1
log MAG
REF -60.0 dB
10.0 dB/
Test Sample D4, t = 0 Hrs.
hp
A
D
1
START 0.500000000 GHz
STOP 1.000000000 GHz

S_{21}/M1 log MAG
REF -60.0 dB
10.0 dB/

Test Sample B1, 0 Hrs.



START 0.500000000 GHz
STOP 1.000000000 GHz

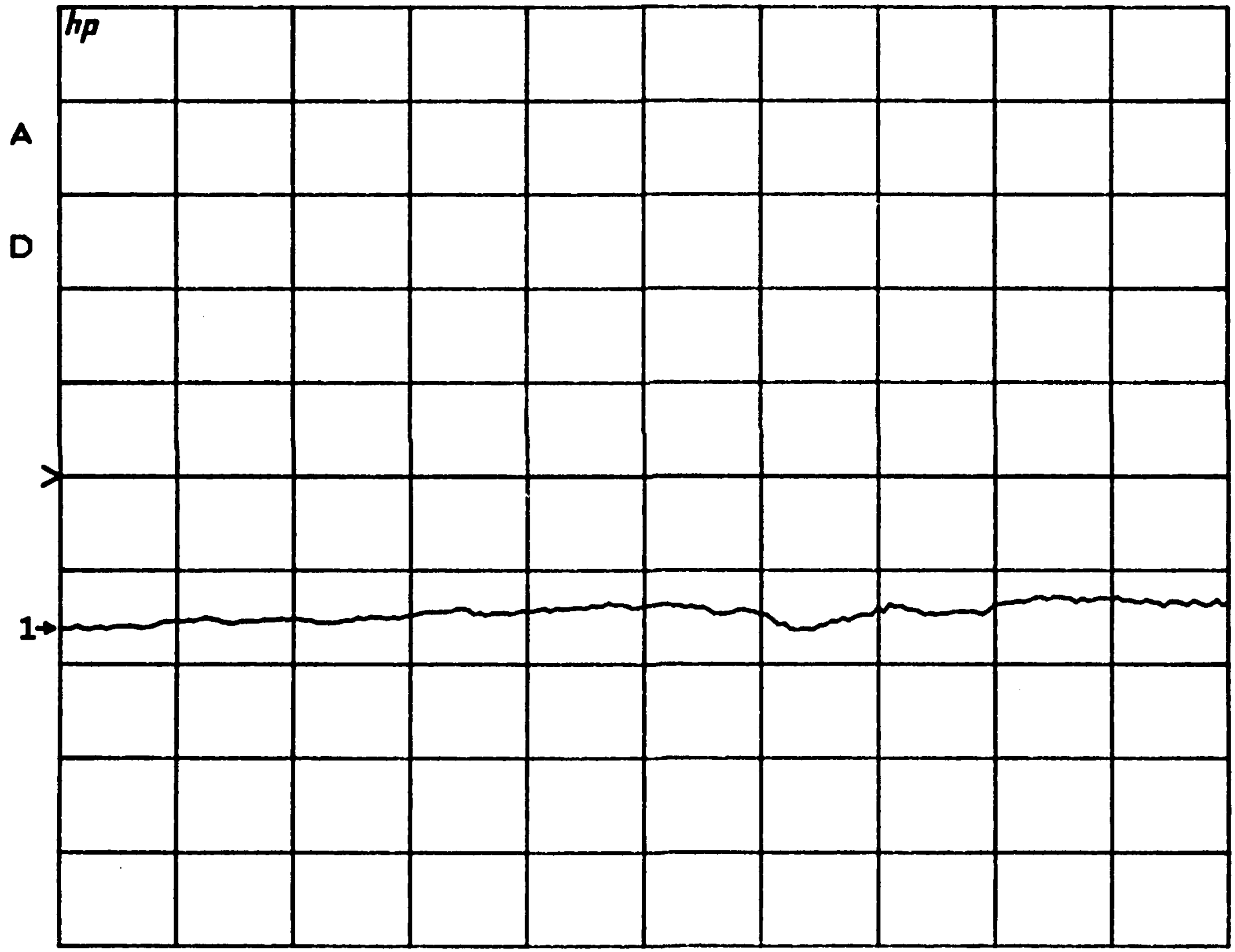


Sample B2, t =0 Hrs.

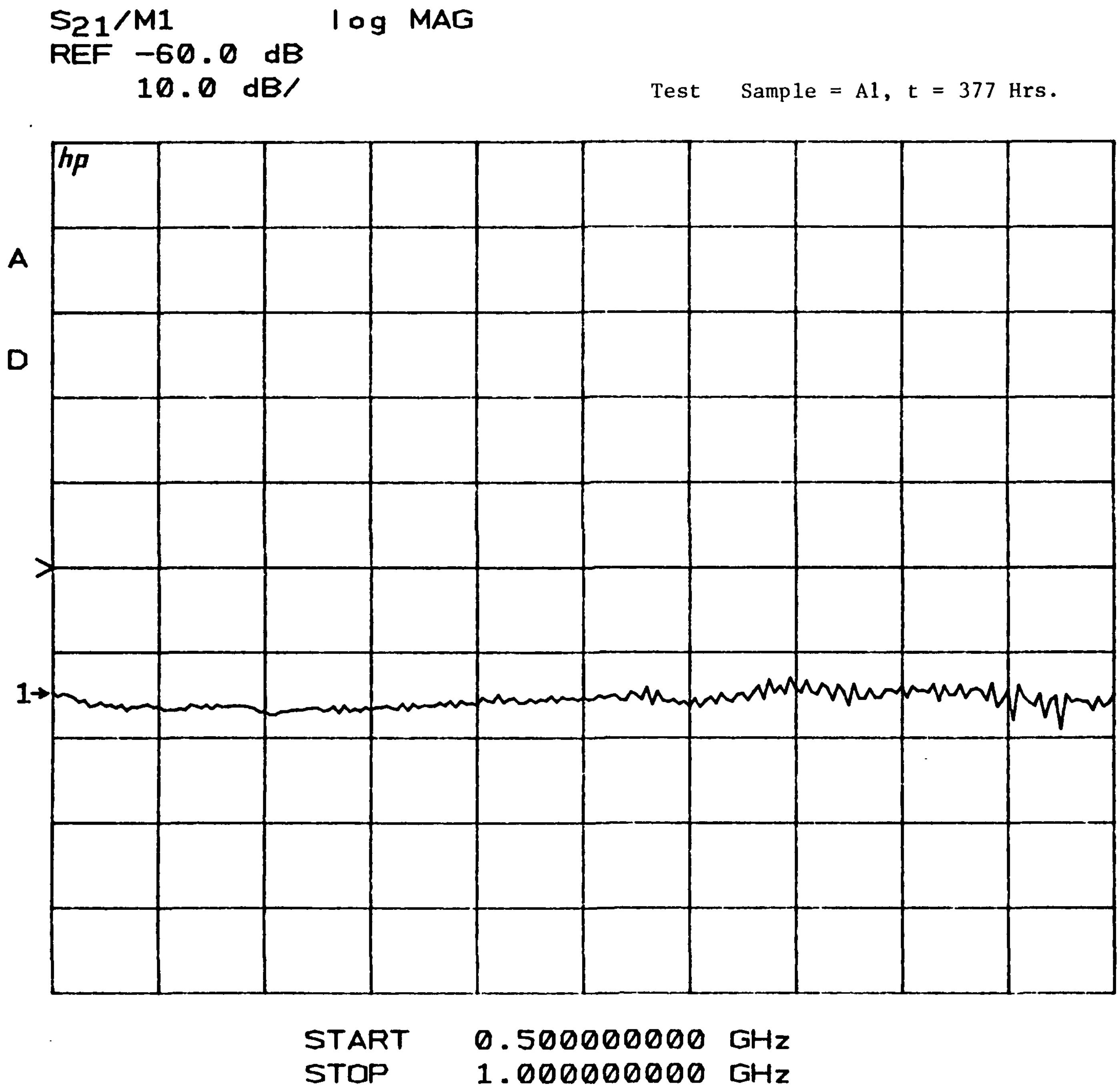
B3

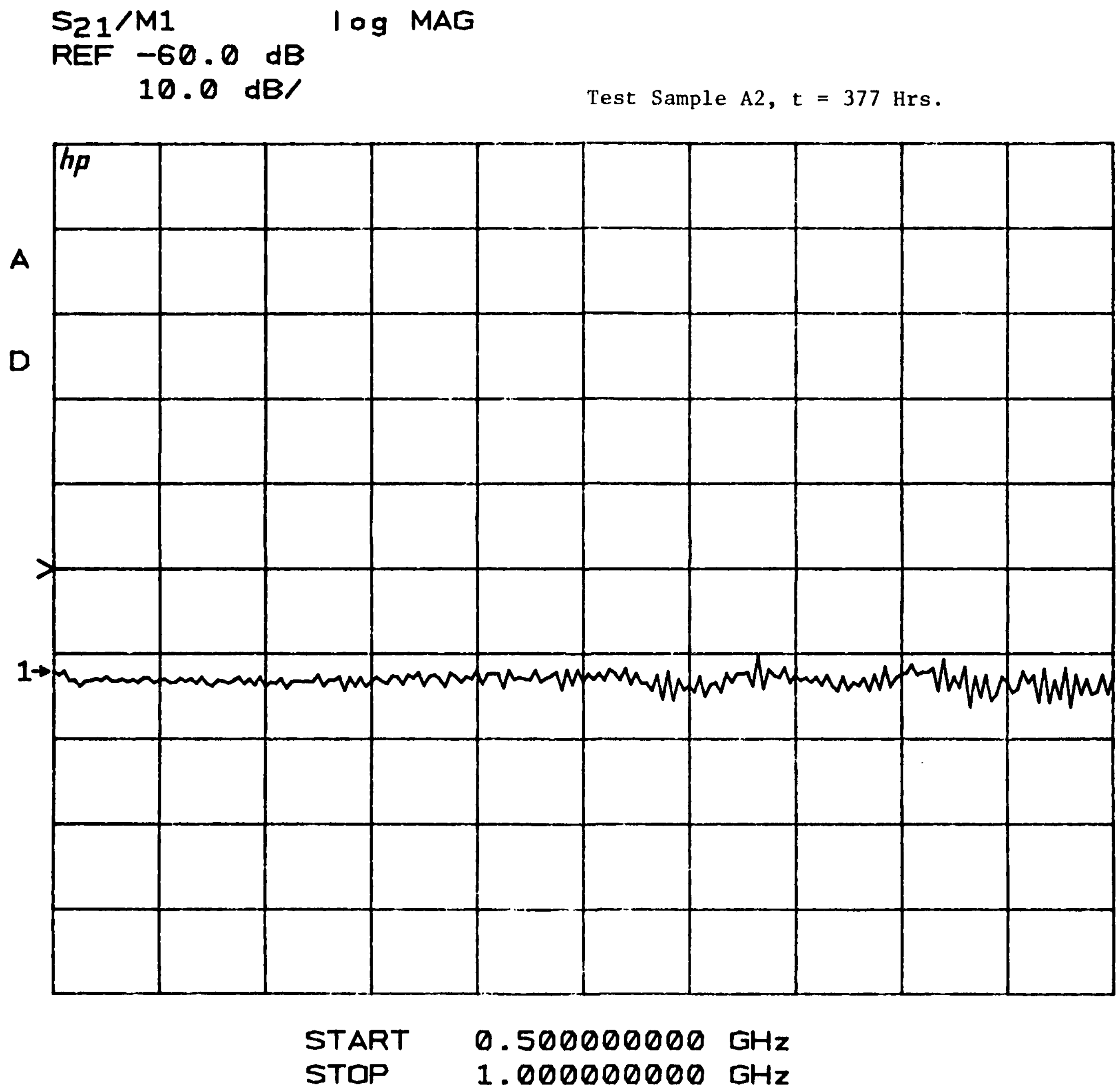
S21/M1 log MAG
REF -60.0 dB
10.0 dB/

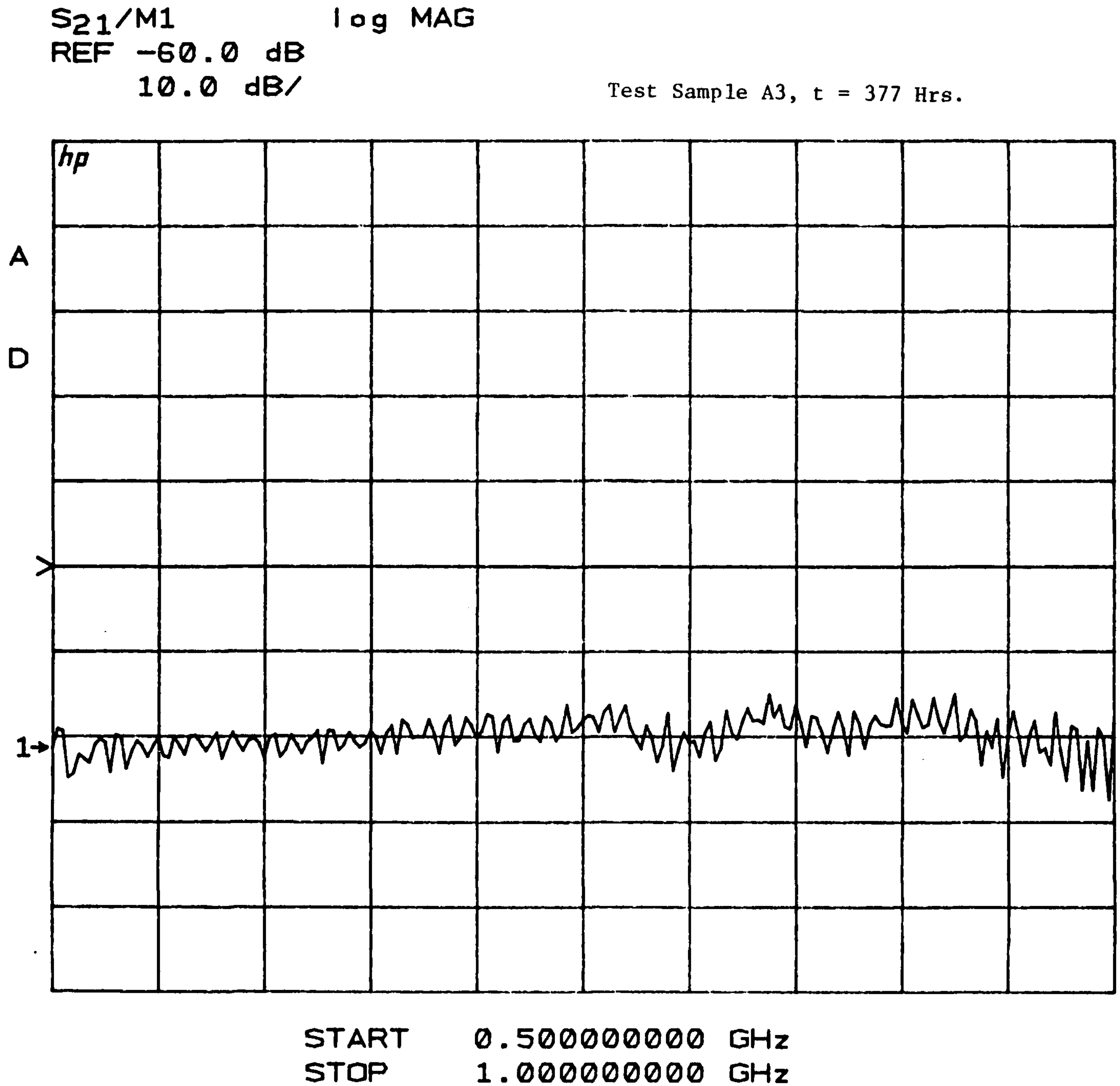
Test Sample B3, t = 0 Hrs.



START 0.500000000 GHz
STOP 1.000000000 GHz

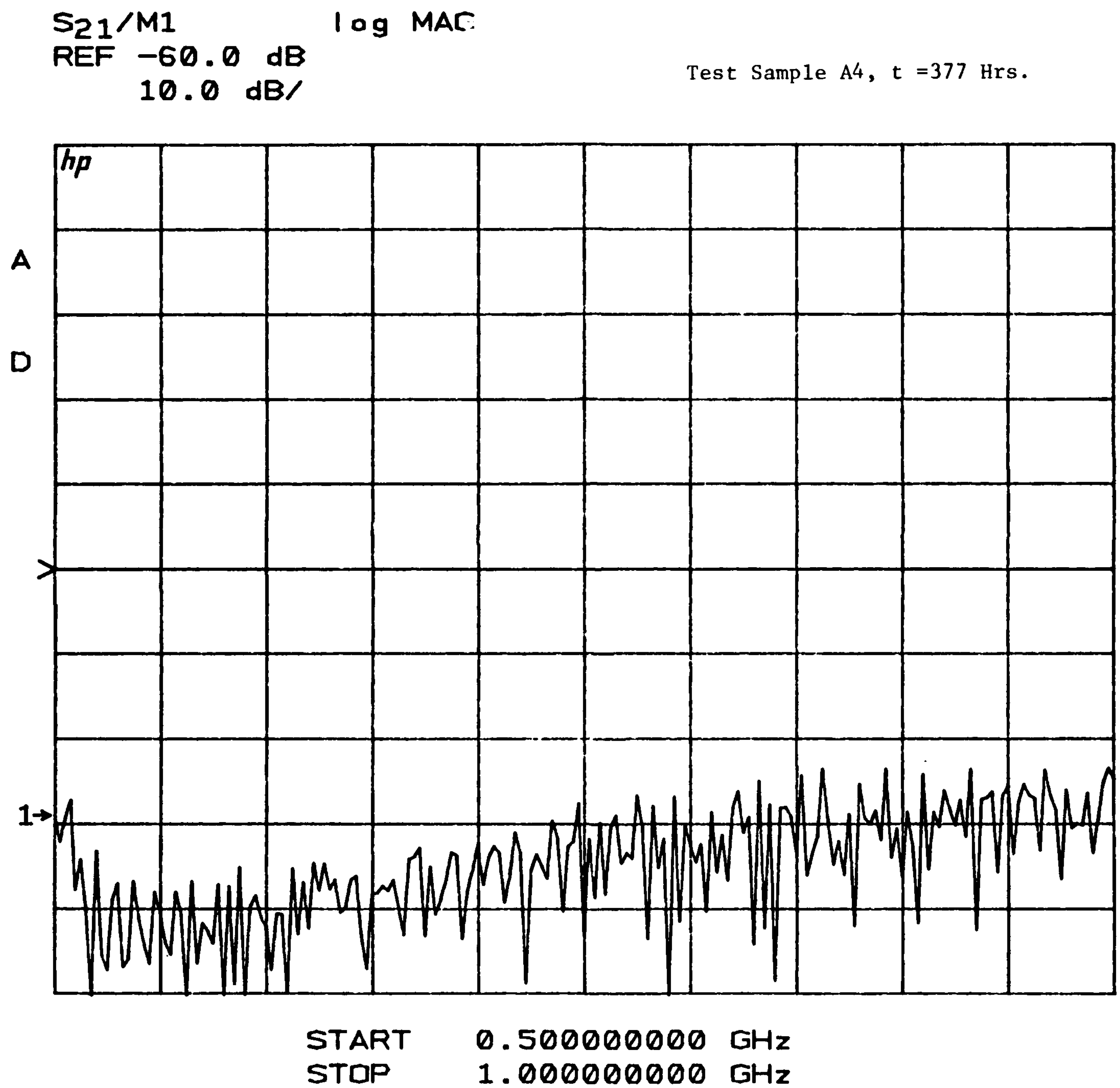

S21/M1
log MAG
REF -60.0 dB
10.0 dB/
Test Sample = A1, t = 377 Hrs.
hp
A
D
1
START 0.500000000 GHz
STOP 1.000000000 GHz

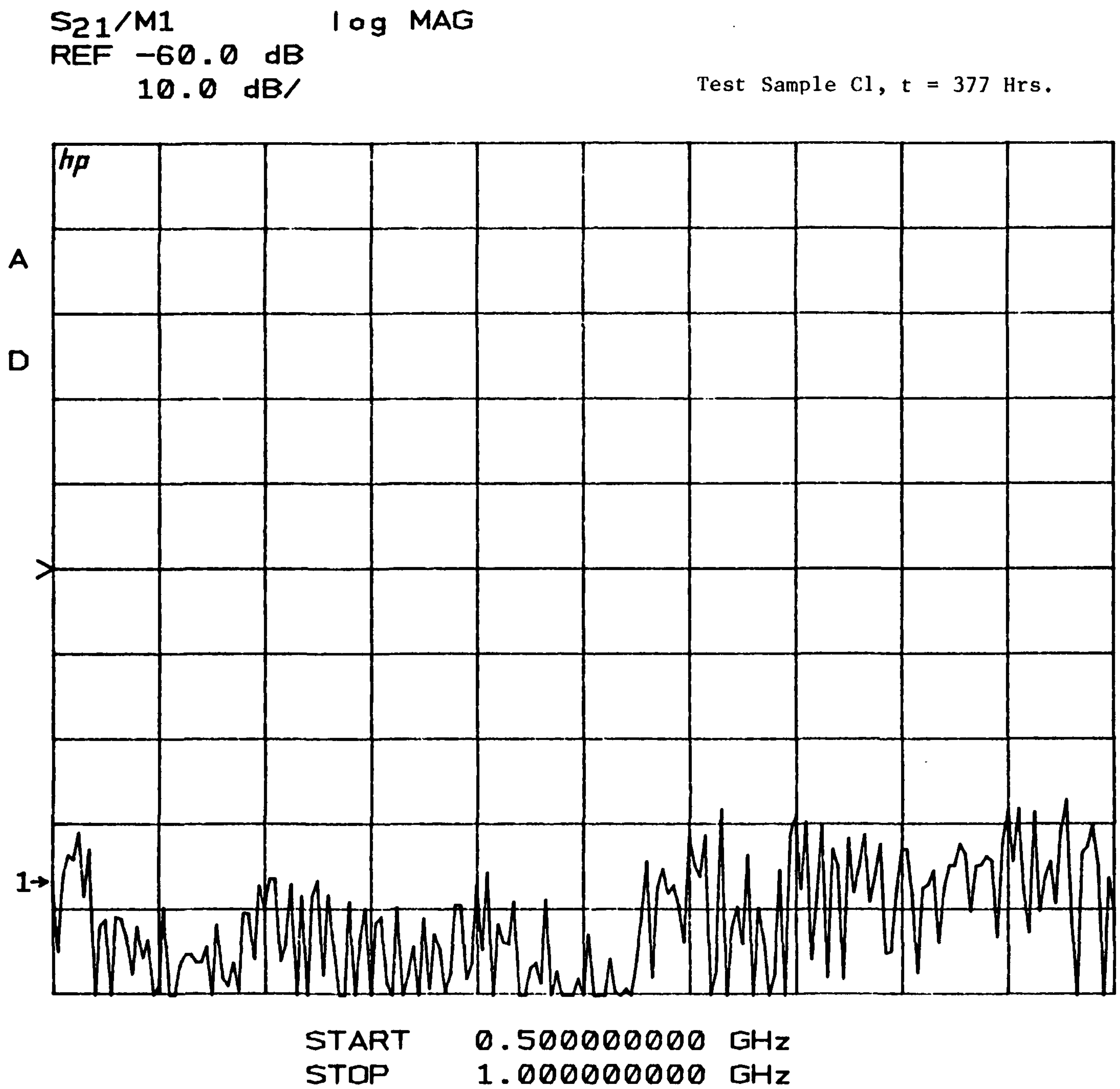

S21/M1
log MAG
REF -60.0 dB
10.0 dB/
Test Sample A2, t = 377 Hrs.
hp
A
D
1
START 0.500000000 GHz
STOP 1.000000000 GHz

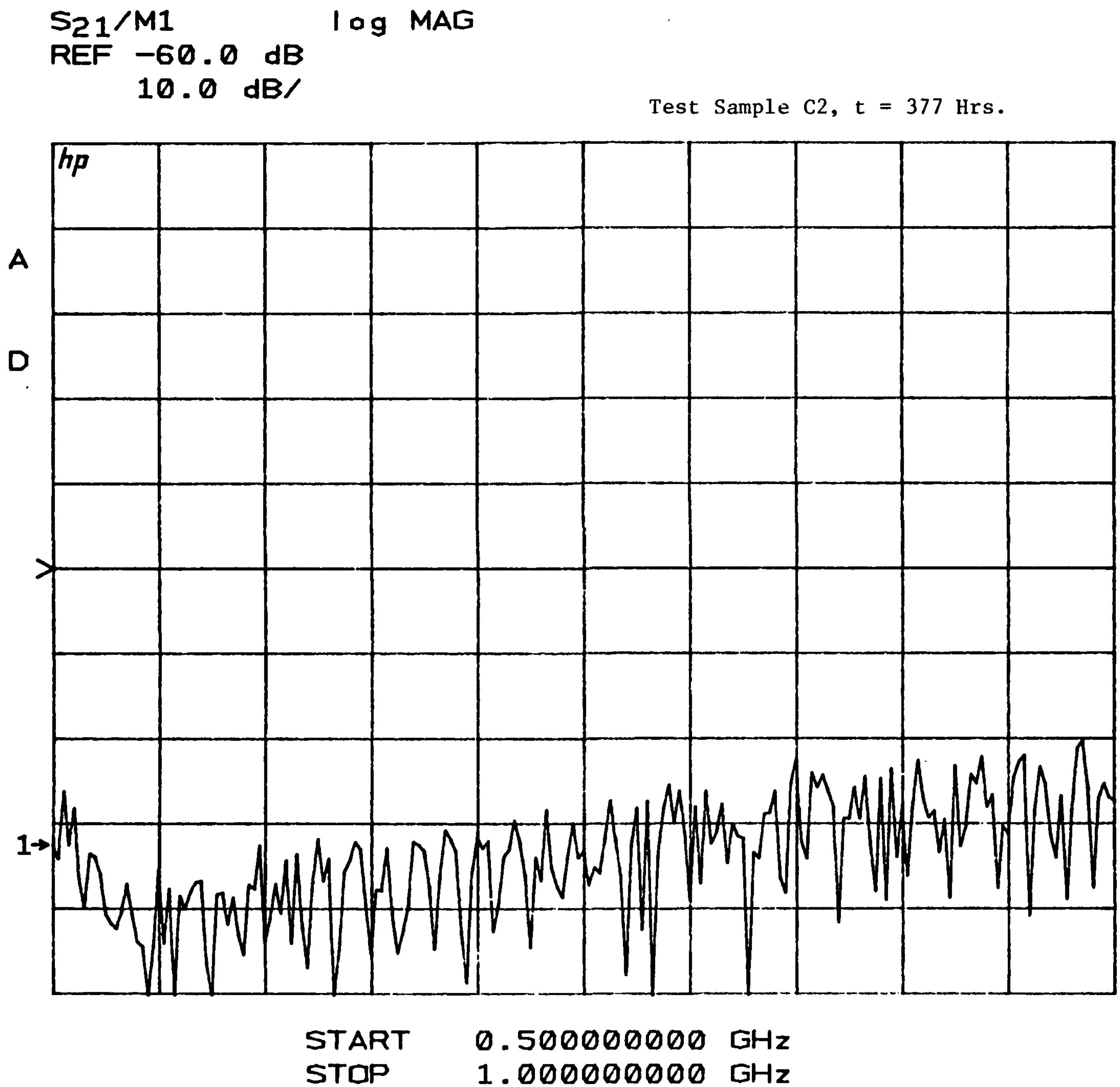


Test Sample A3, t = 377 Hrs.

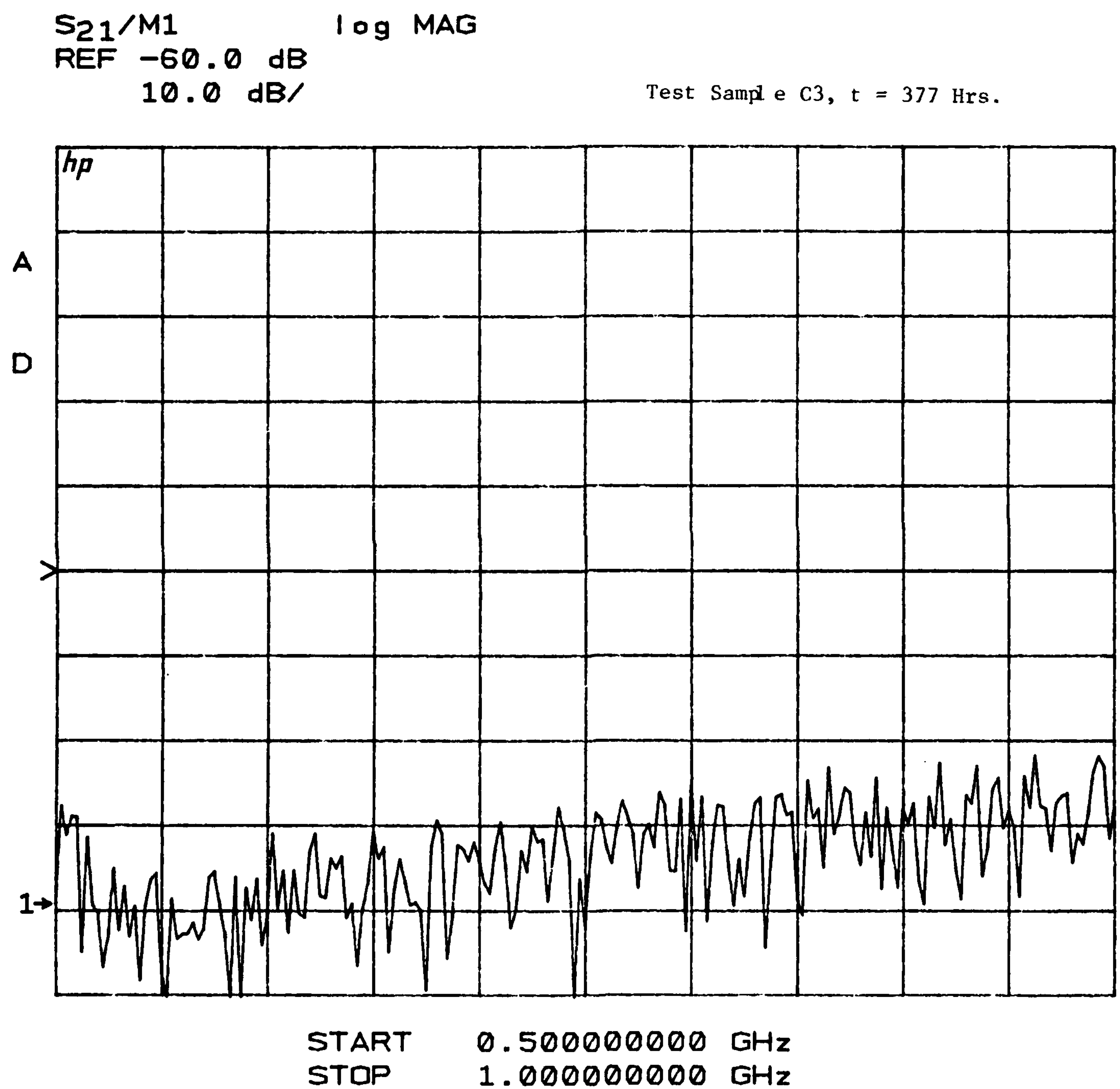
Test Sample A4, t =377 Hrs.

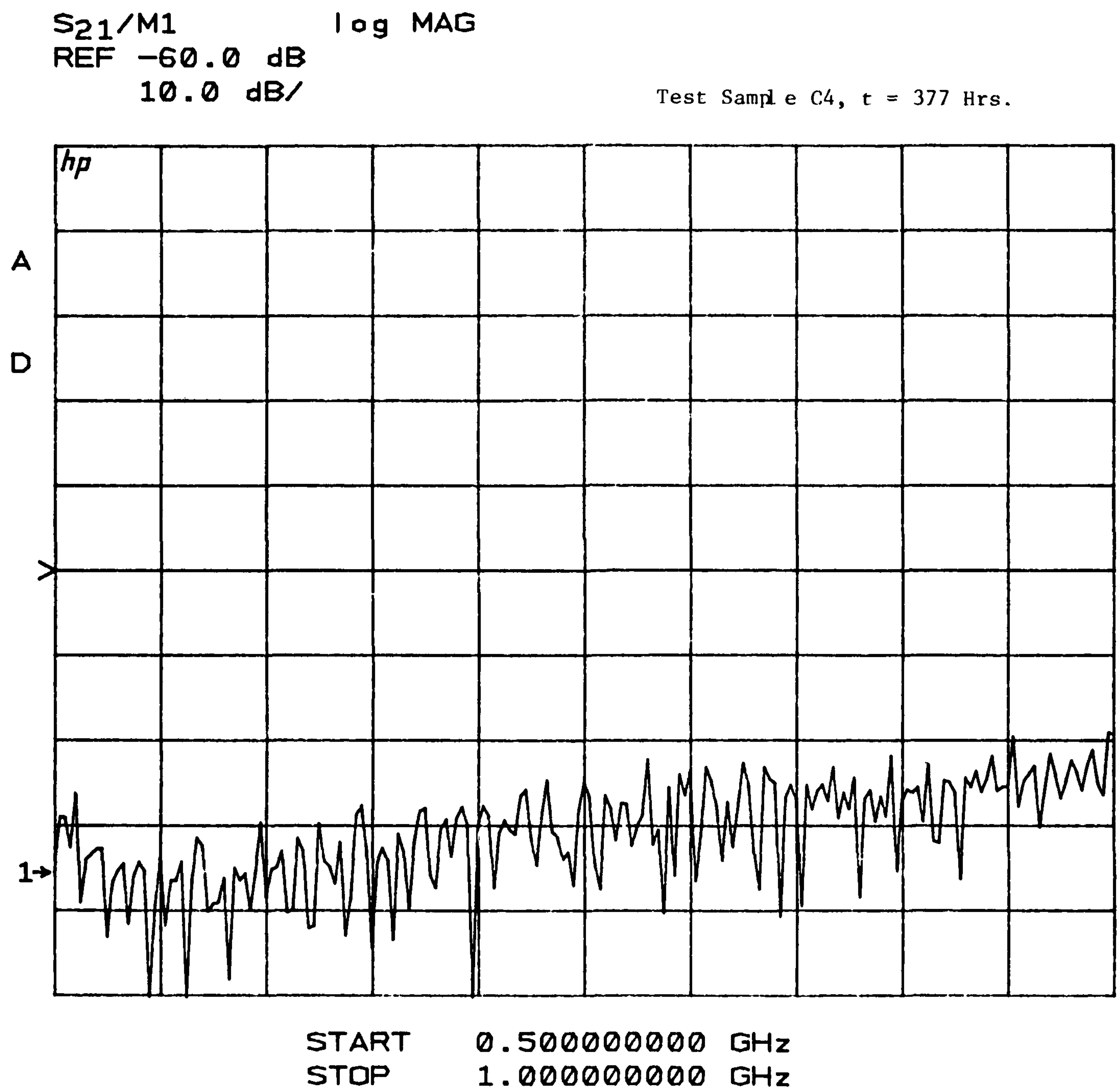


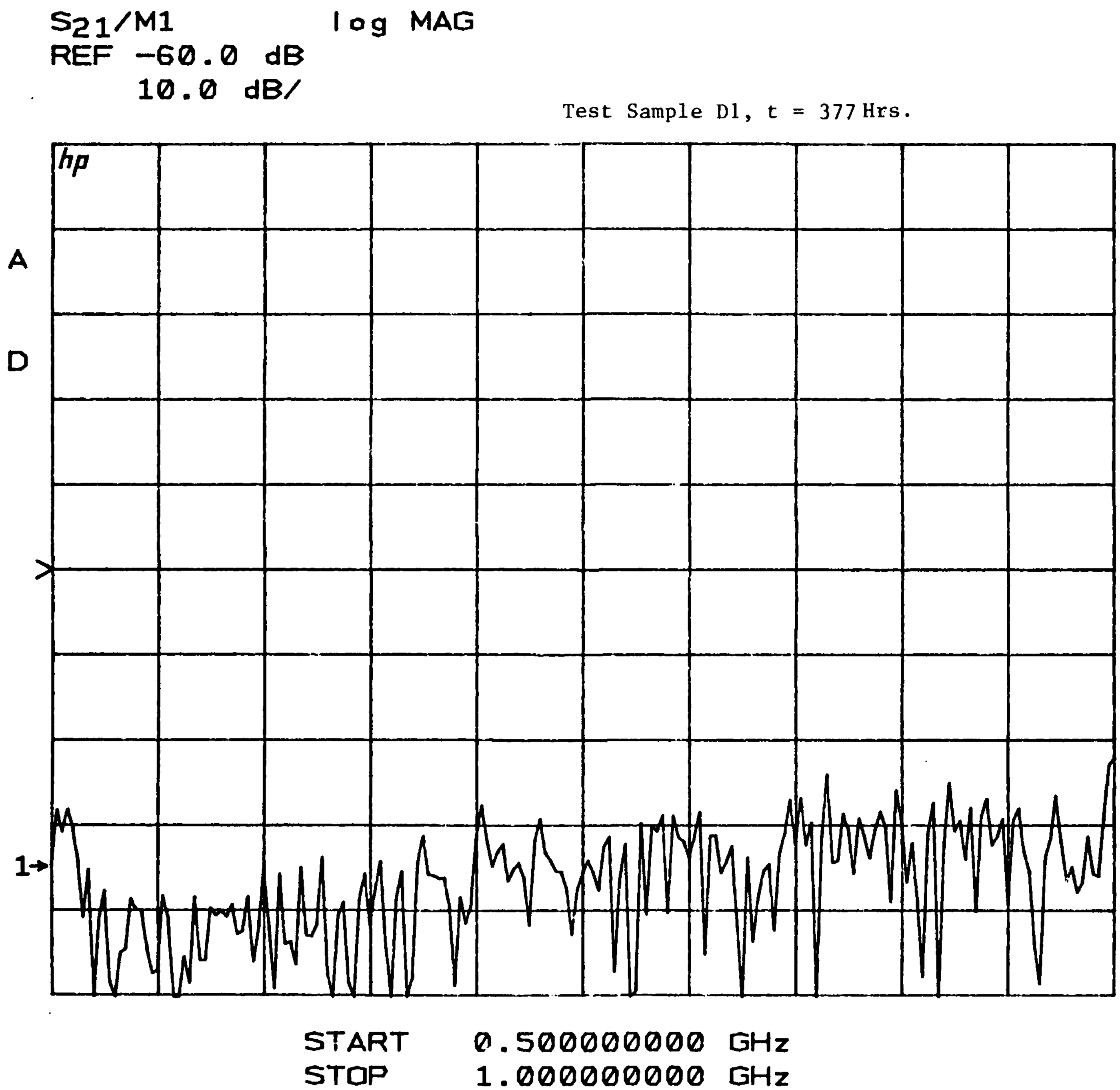

S21/M1 log MAG
REF -60.0 dB
10.0 dB/
Test Sample Cl, t = 377 Hrs.
hp
A
D
1→
START 0.500000000 GHz
STOP 1.000000000 GHz

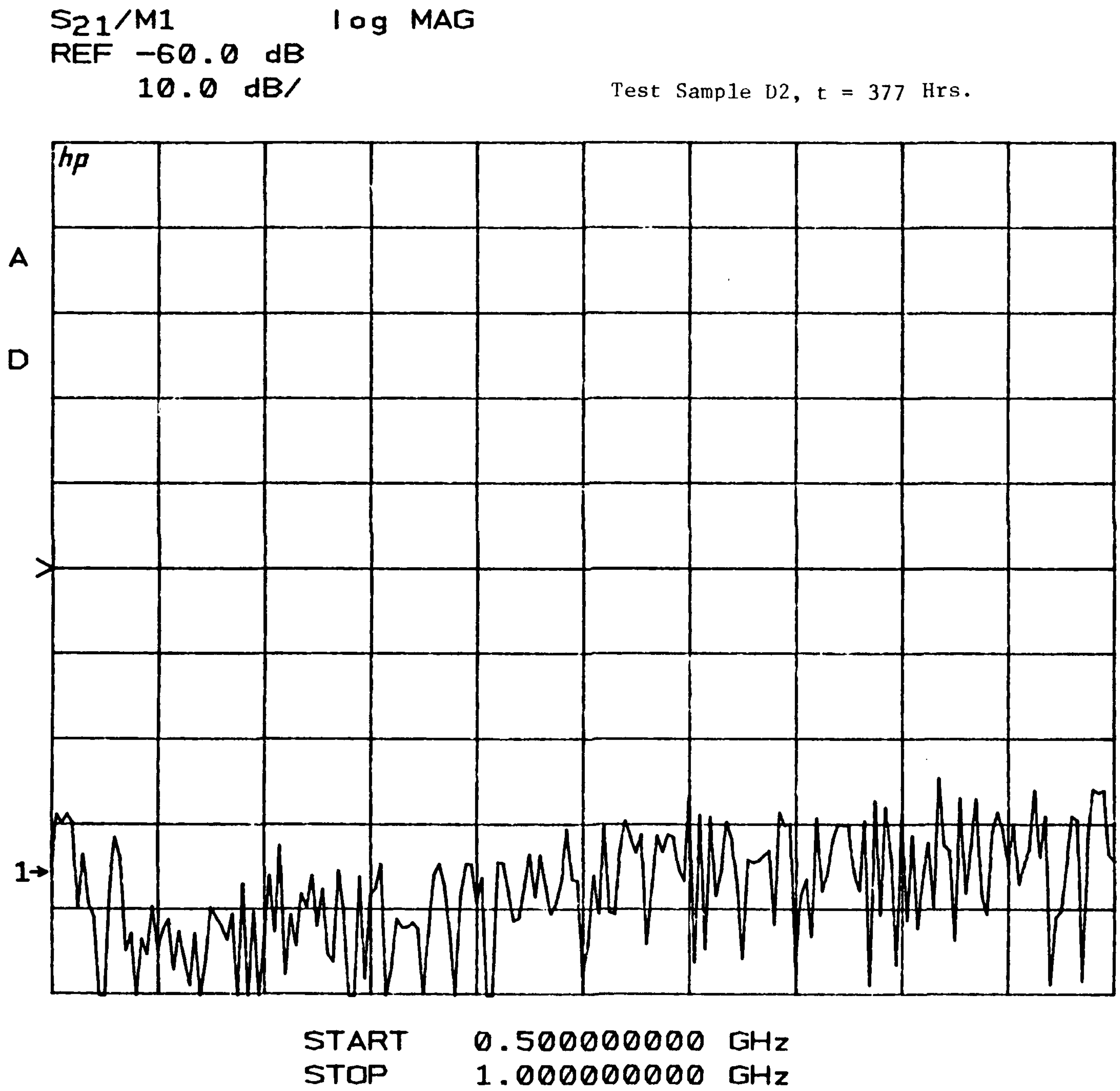


Test Sample C2, t = 377 Hrs.

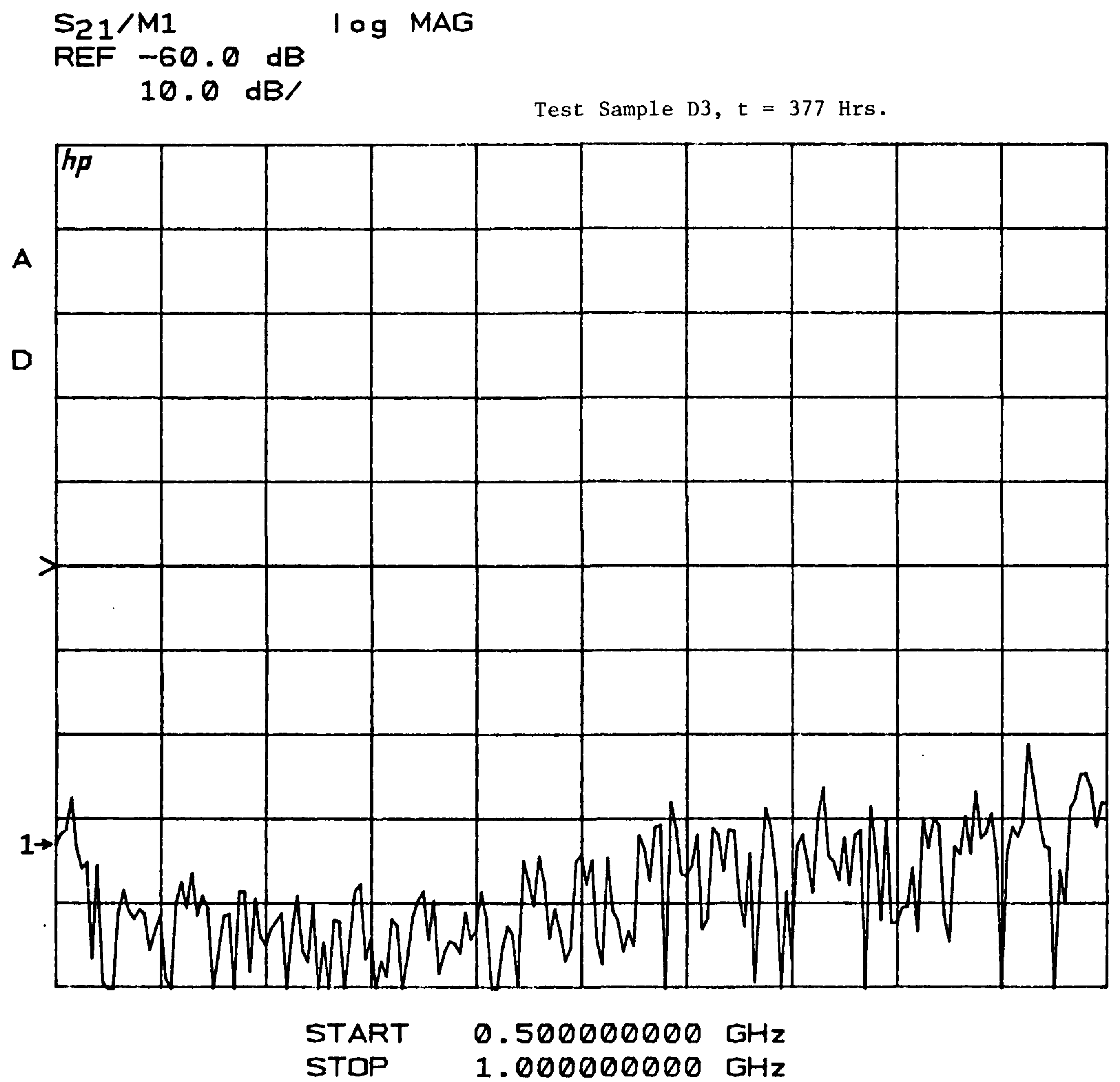

S21/M1 log MAG
REF -60.0 dB
10.0 dB/
Test Sample C3, t = 377 Hrs.
hp
A
D
1
START 0.500000000 GHz
STOP 1.000000000 GHz


S21/M1 log MAG
REF -60.0 dB
10.0 dB/
Test Sample C4, t = 377 Hrs.
hp
A
D
1→
START 0.500000000 GHz
STOP 1.000000000 GHz

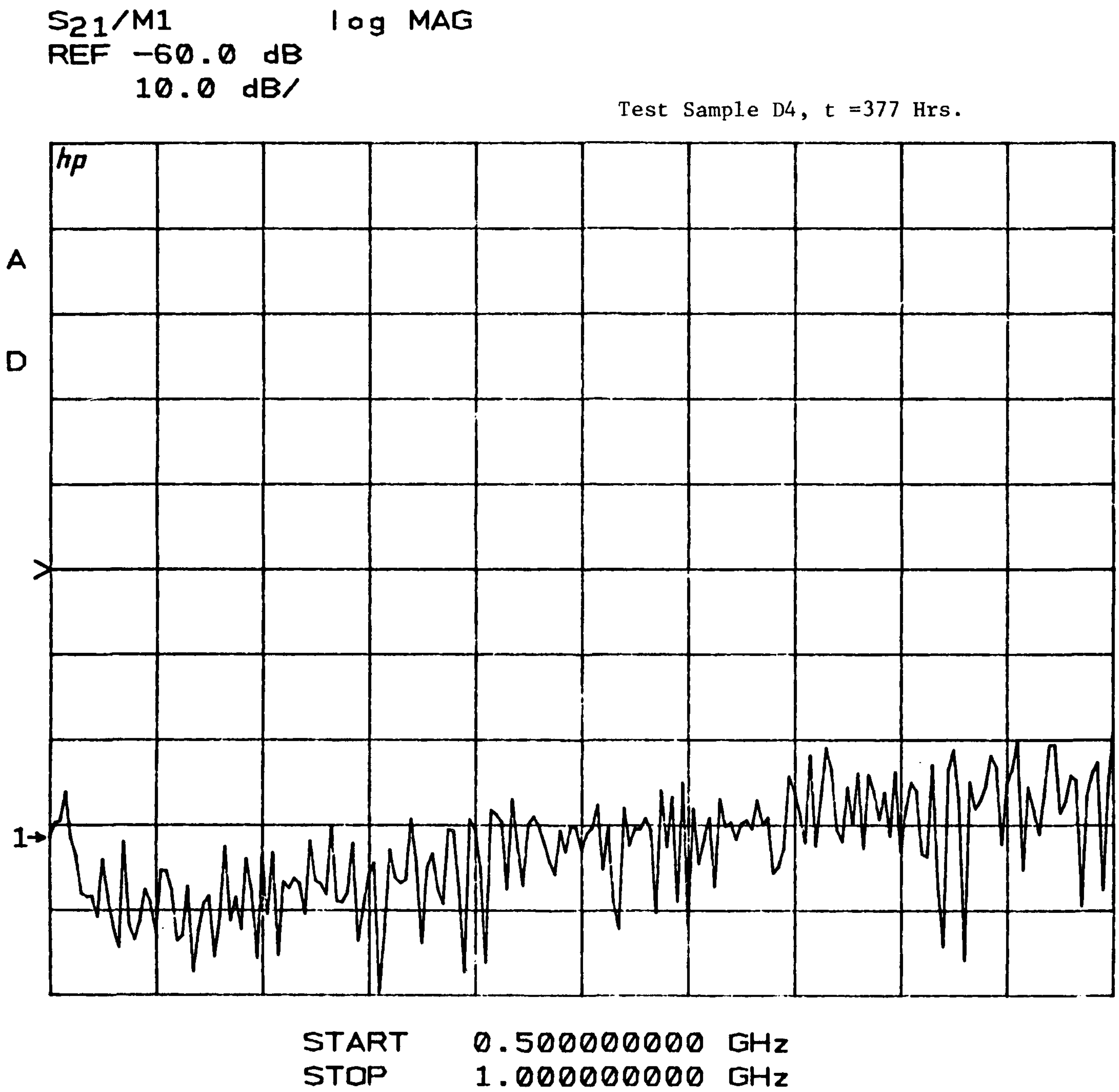

S21/M1
log MAG
REF -60.0 dB
10.0 dB/
Test Sample D1, t = 377 Hrs.
hp
A
D
1→
START 0.500000000 GHz
STOP 1.000000000 GHz



S_{21}/M1 log MAG
REF -60.0 dB
10.0 dB/
Test Sample D2, t = 377 Hrs.
hp
A
D
1→
START 0.500000000 GHz
STOP 1.000000000 GHz

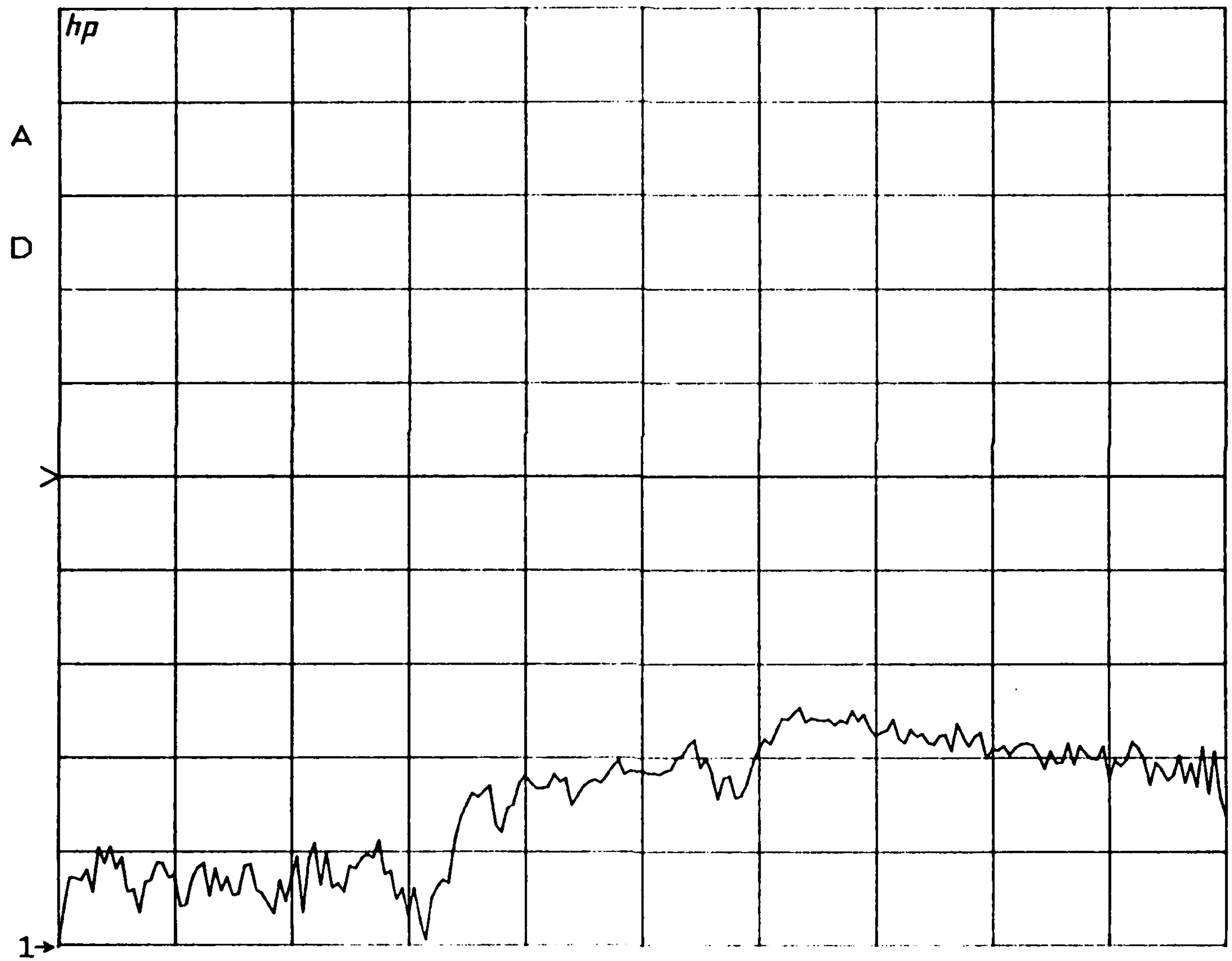


S21/M1 log MAG
REF -60.0 dB
10.0 dB/
Test Sample D3, t = 377 Hrs.
hp
A
D
1→
START 0.500000000 GHz
STOP 1.000000000 GHz


S21/M1 log MAG
REF -60.0 dB
10.0 dB/
Test Sample D4, t =377 Hrs.
hp
A
D
1
START 0.500000000 GHz
STOP 1.000000000 GHz

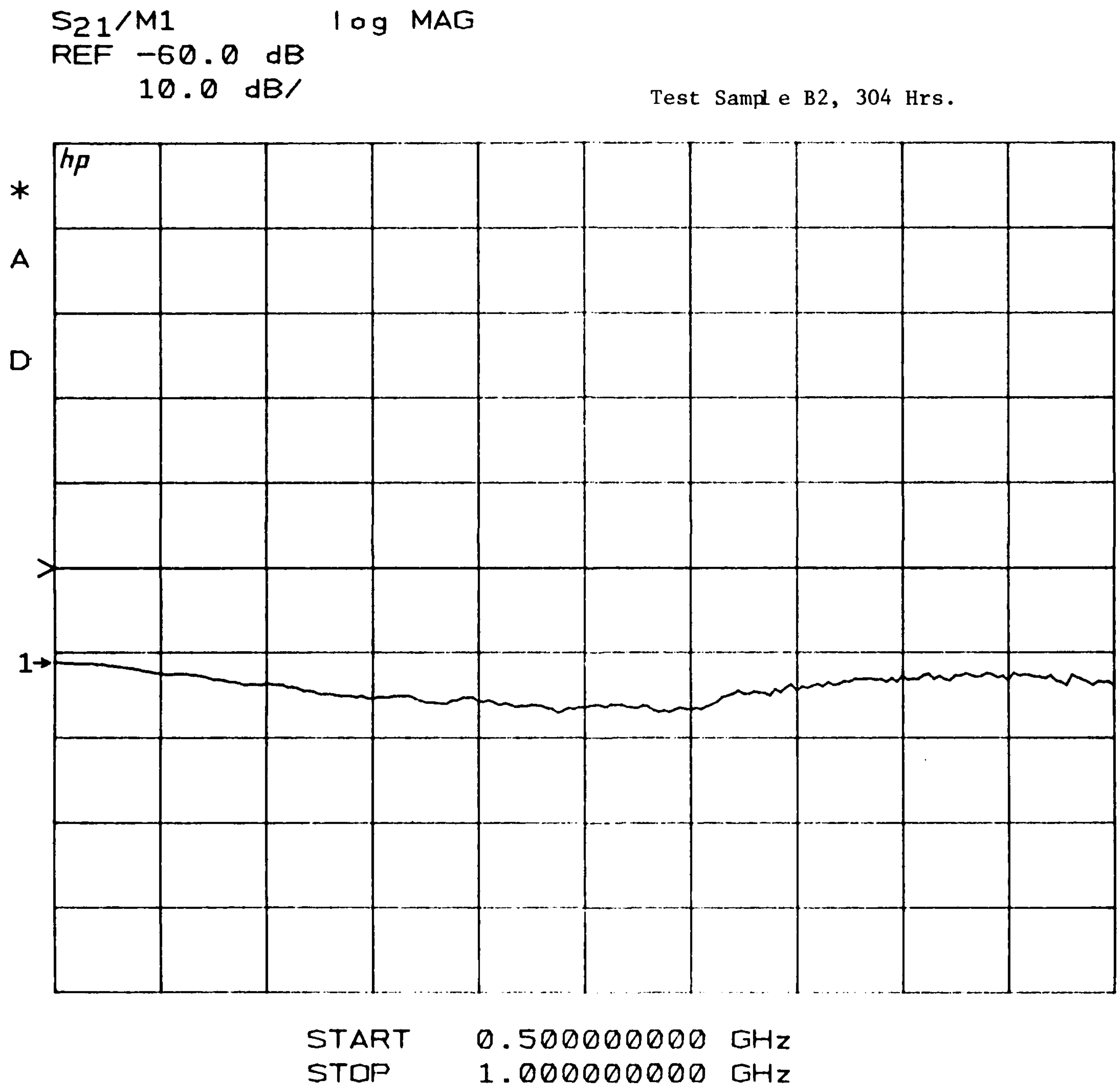
S21/M1 log MAG
REF -60.0 dB
10.0 dB/

Test Sample B1, t = 304 Hrs.



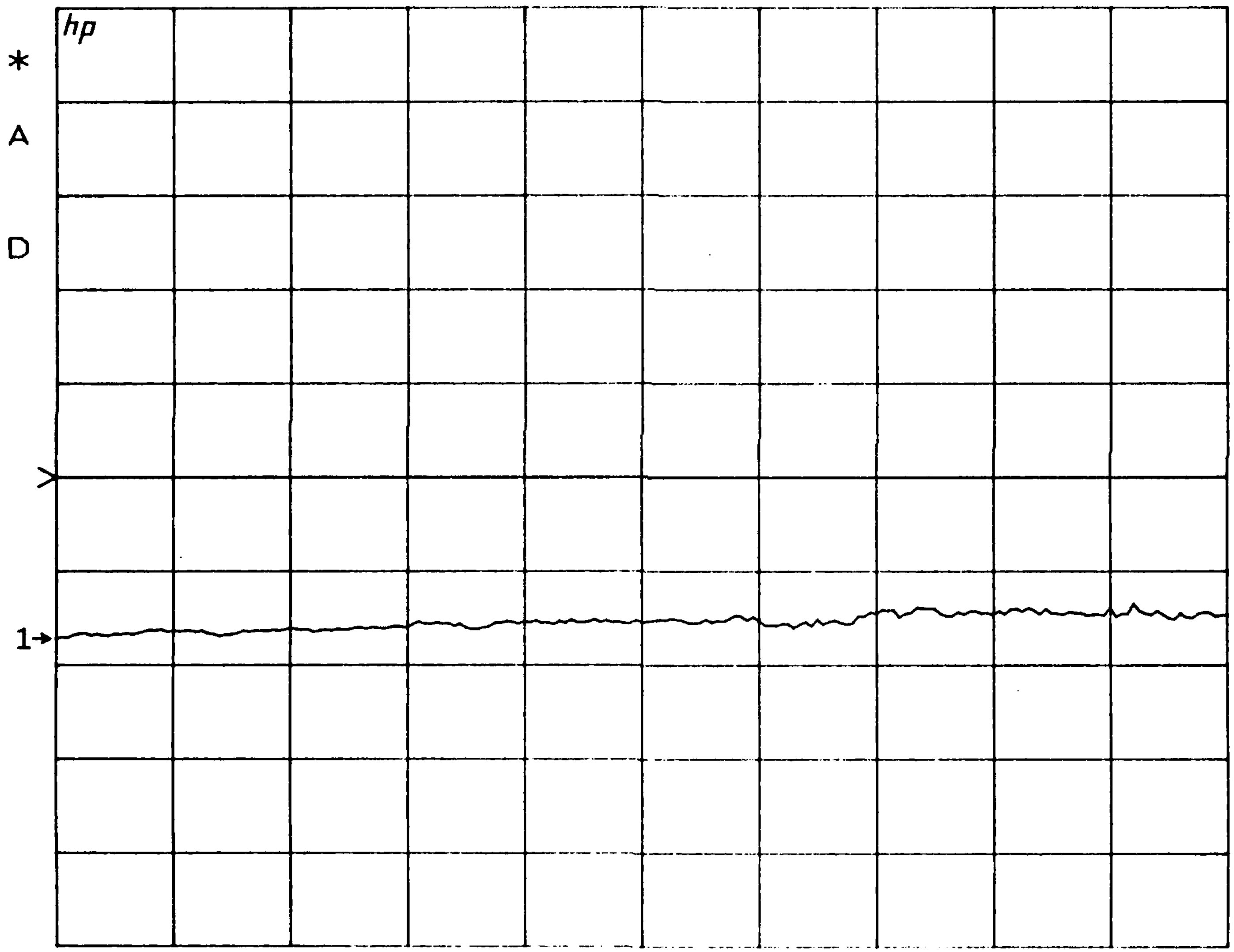
START 0.500000000 GHz
STOP 1.000000000 GHz

Test Sample B2, 304 Hrs.

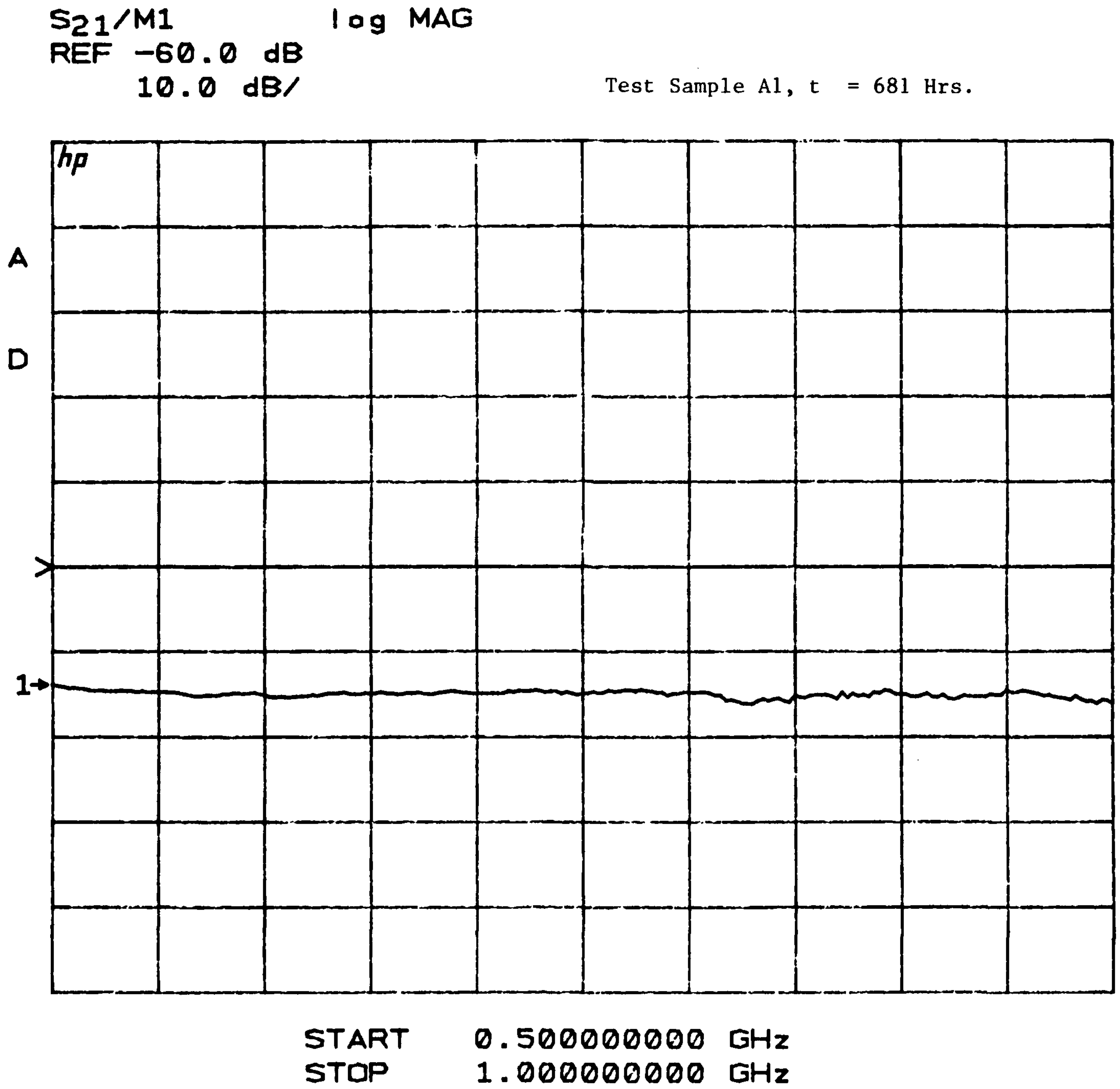


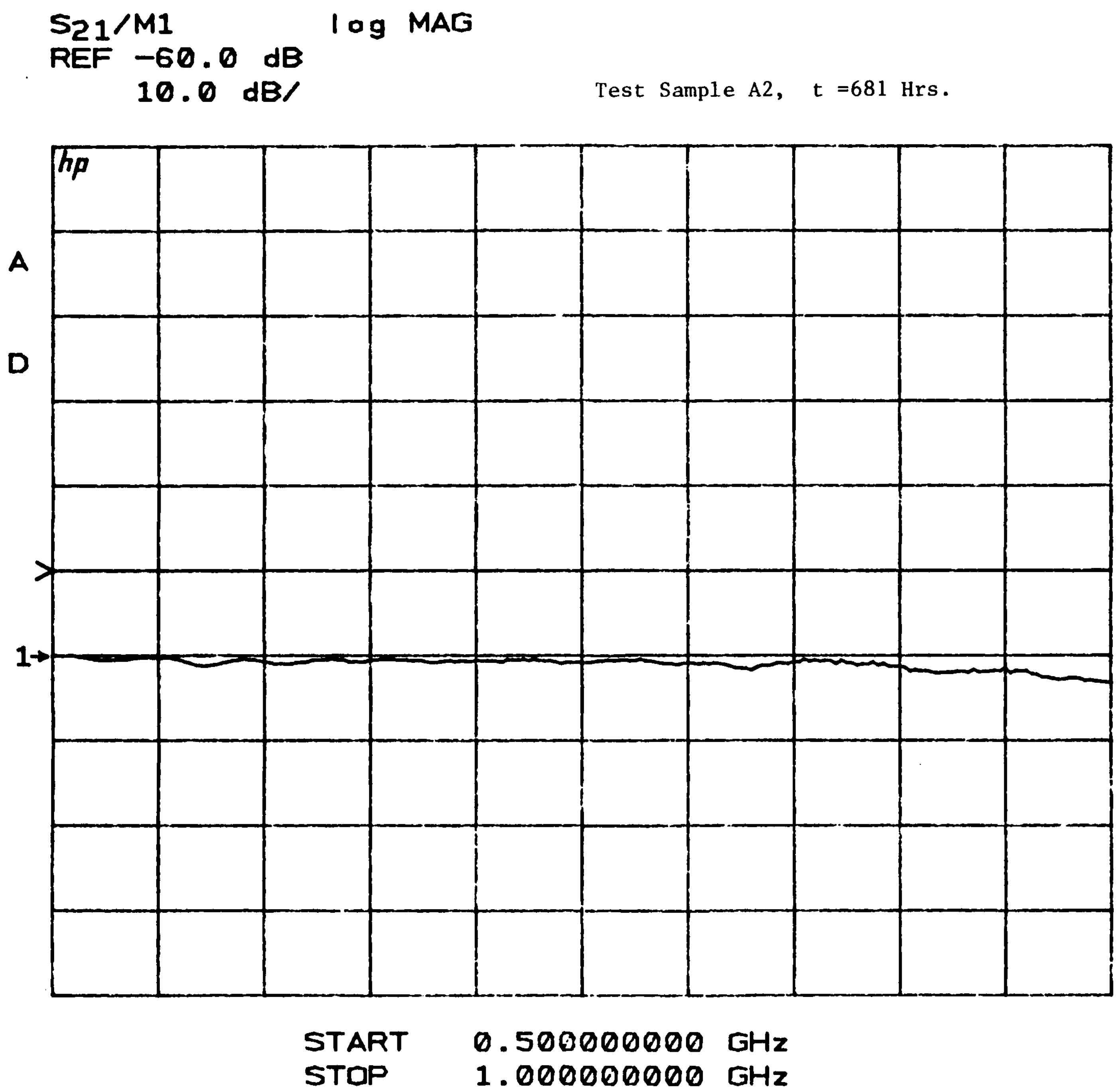
S21/M1 log MAG
REF -60.0 dB
10.0 dB/

Test Sample B3, t = 304 Hrs.

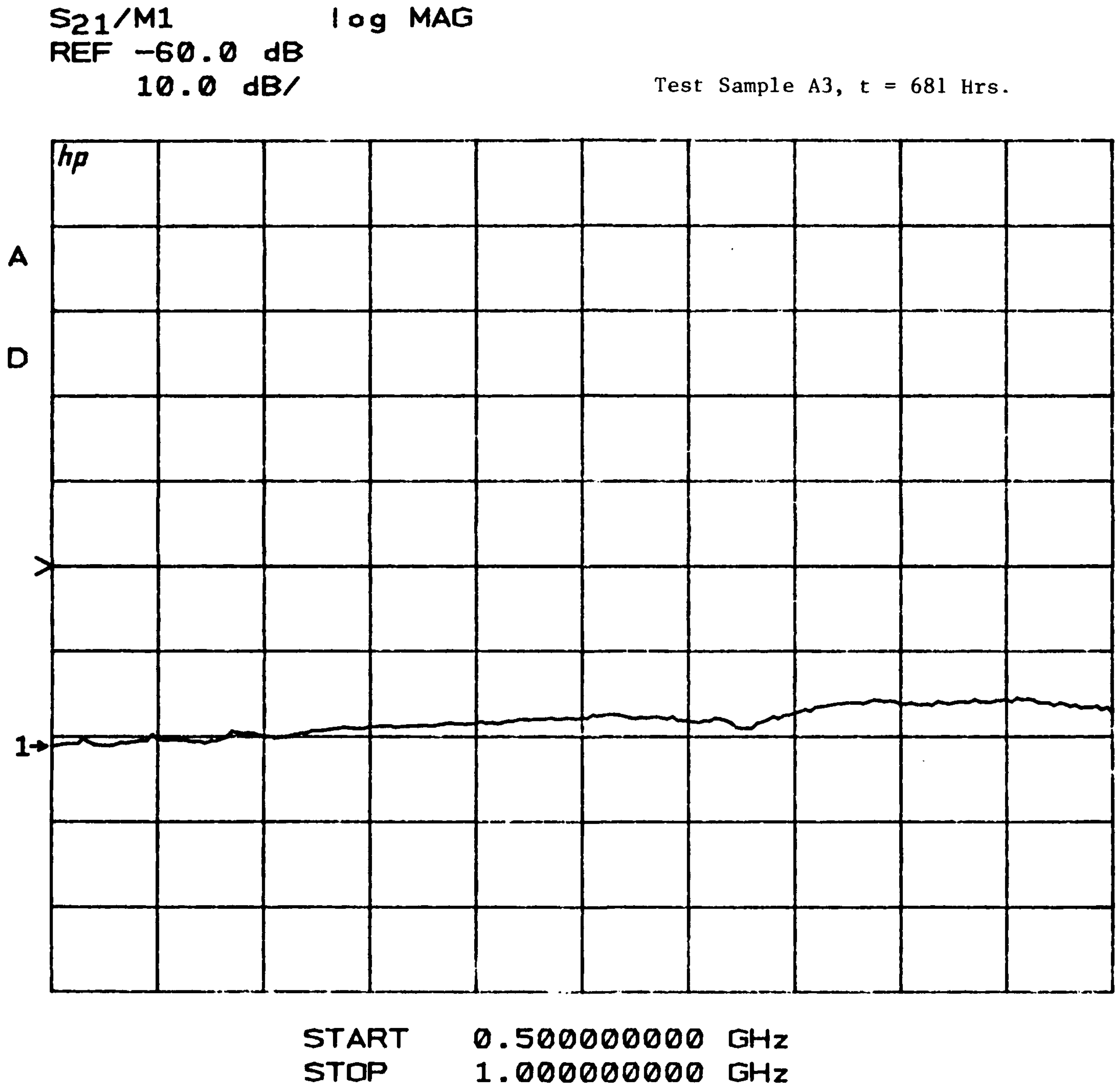


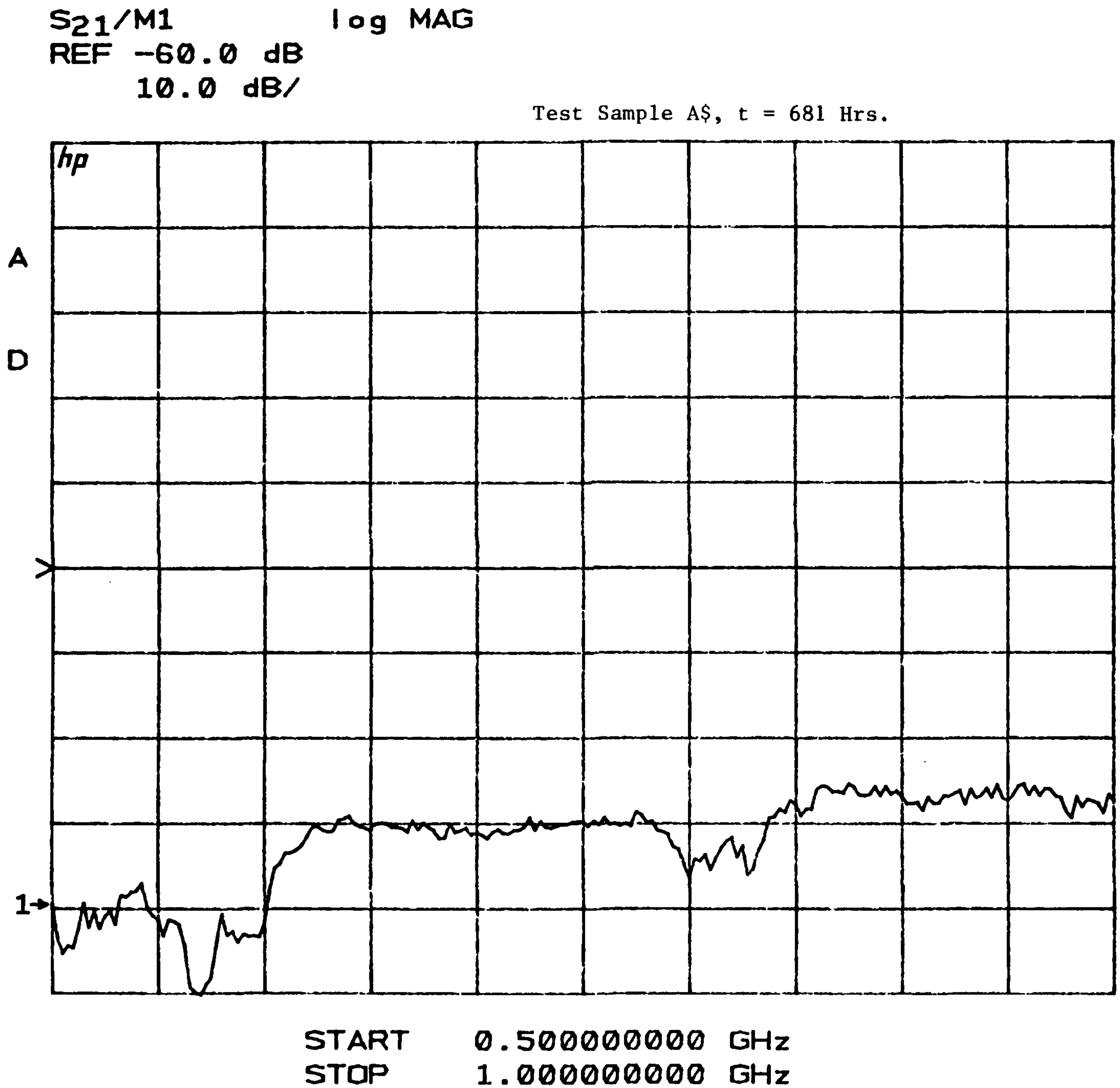
START 0.500000000 GHz
STOP 1.000000000 GHz

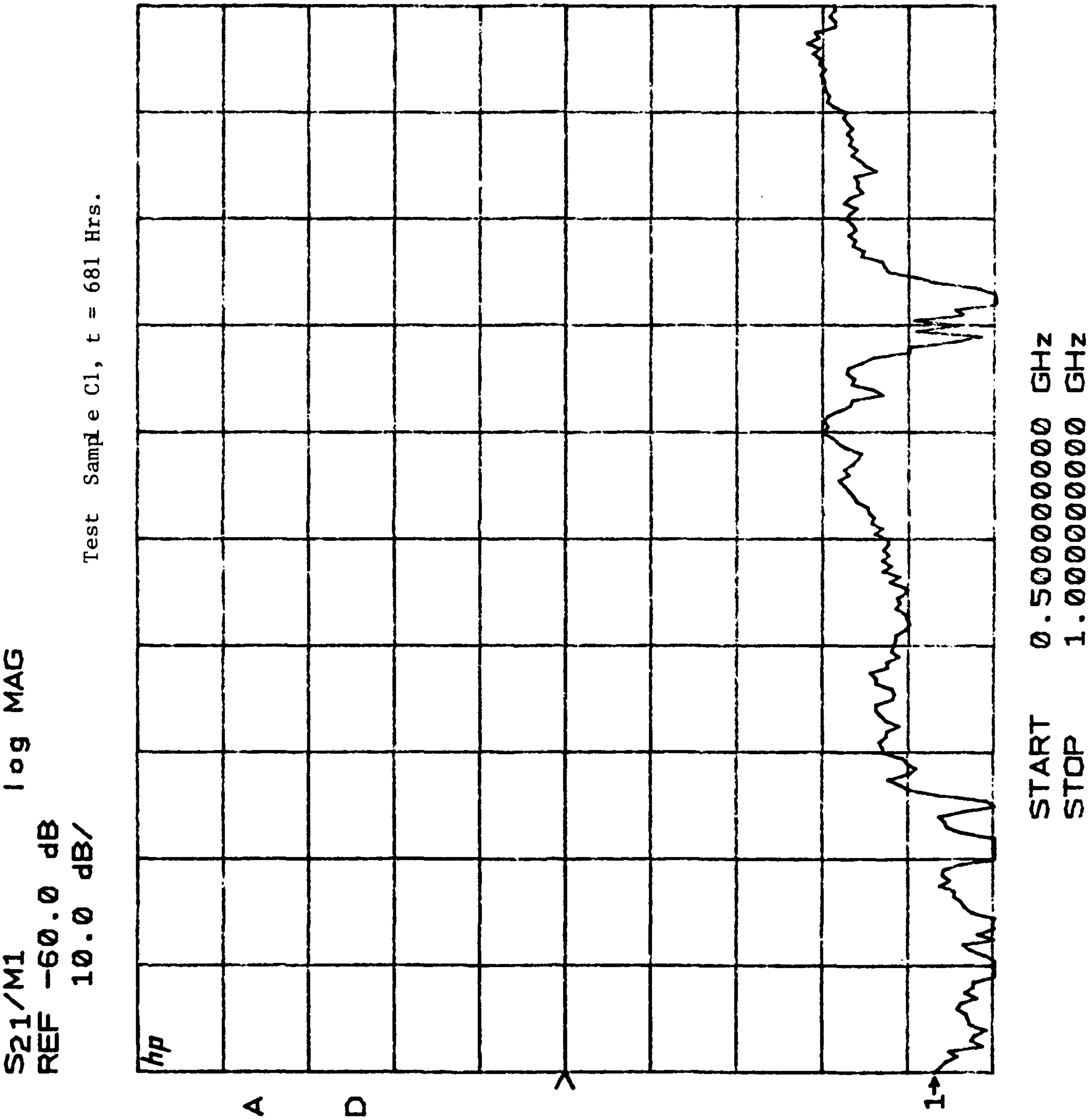

S_{21}/M1 log MAG
REF −60.0 dB
10.0 dB/
Test Sample A1, t = 681 Hrs.
hp
A
D
1
START 0.500000000 GHz
STOP 1.000000000 GHz



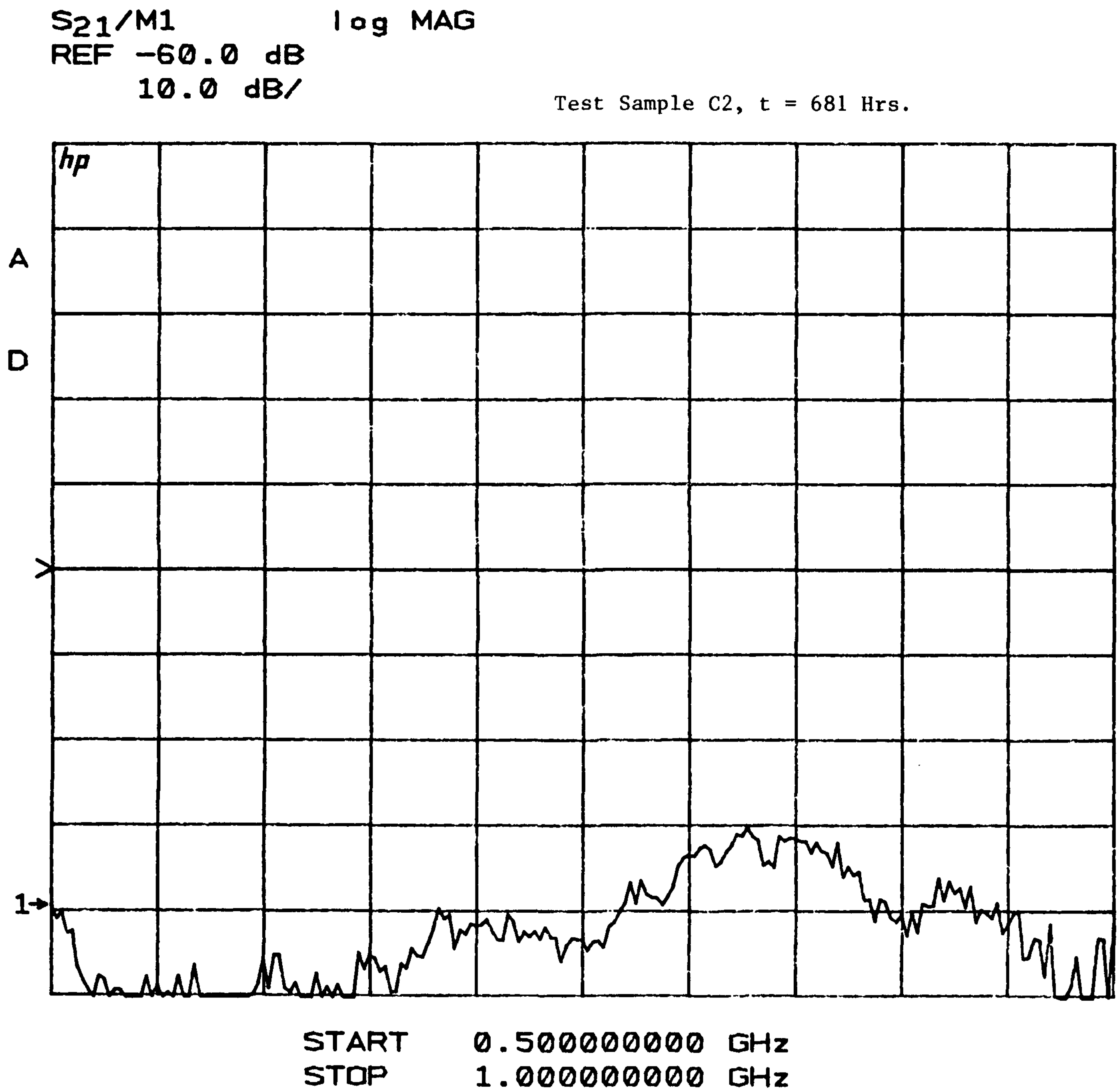
S21/M1
log MAG
REF -60.0 dB
10.0 dB/
Test Sample A2, t =681 Hrs.
hp
A
D
1
START 0.500000000 GHz
STOP 1.000000000 GHz

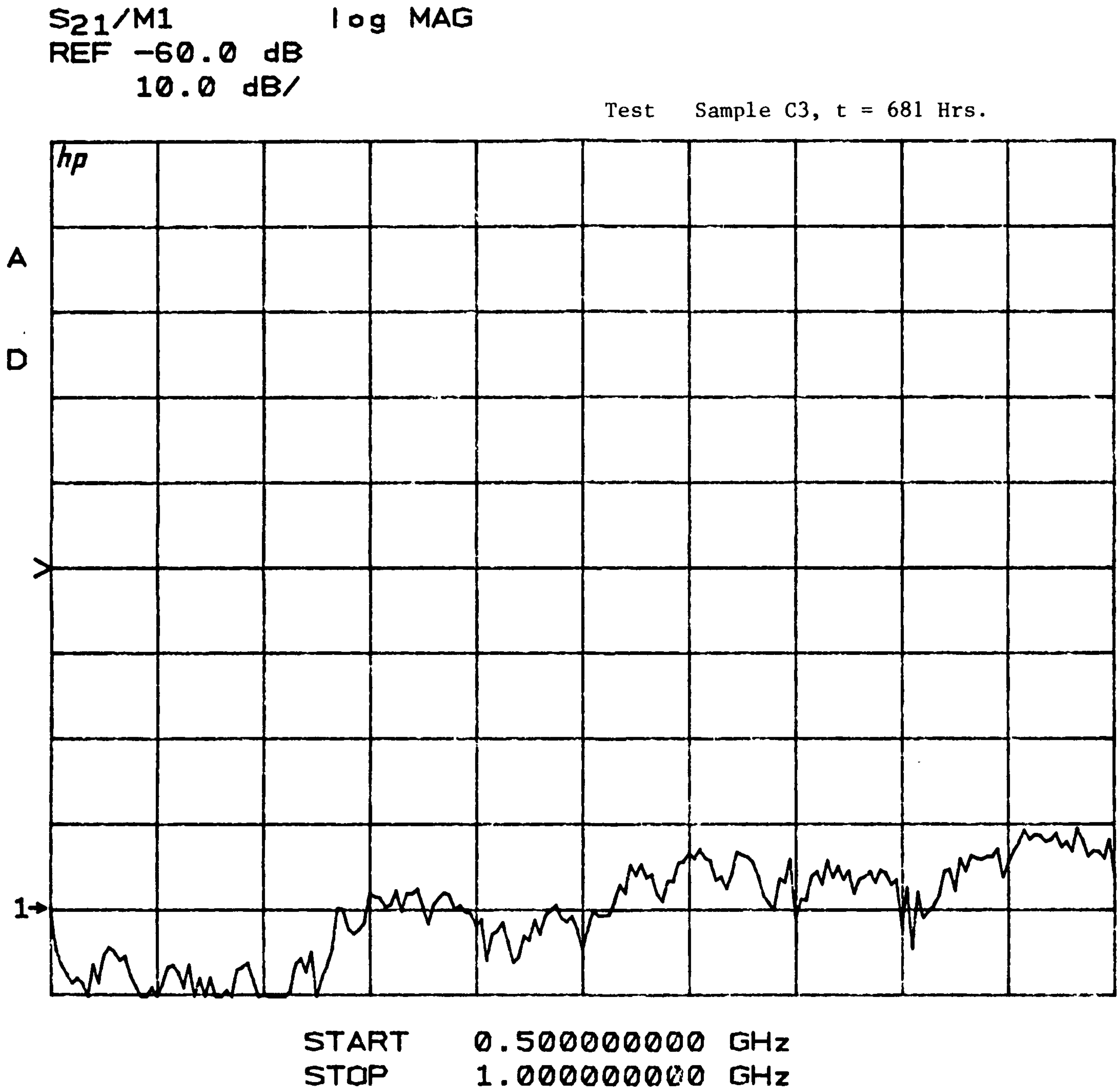

S21/M1 log MAG
REF -60.0 dB
10.0 dB/
Test Sample A3, t = 681 Hrs.
hp
A
D
1
START 0.500000000 GHz
STOP 1.000000000 GHz


S_{21}/M1 log MAG
REF −60.0 dB
10.0 dB/
Test Sample A$, t = 681 Hrs.
hp
A
D
1→
START 0.500000000 GHz
STOP 1.000000000 GHz



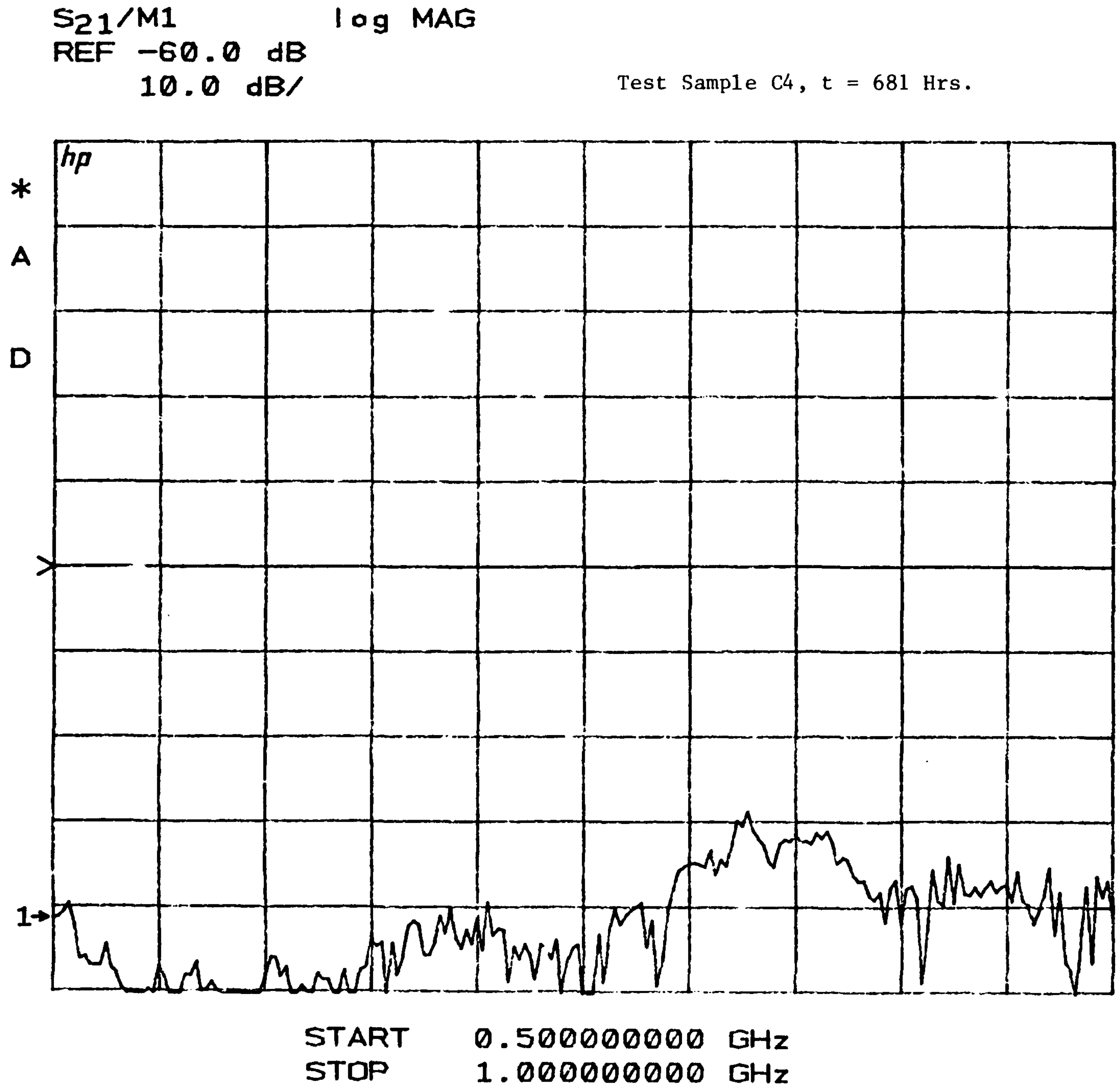
Test Sampl e C1, t = 681 Hrs.

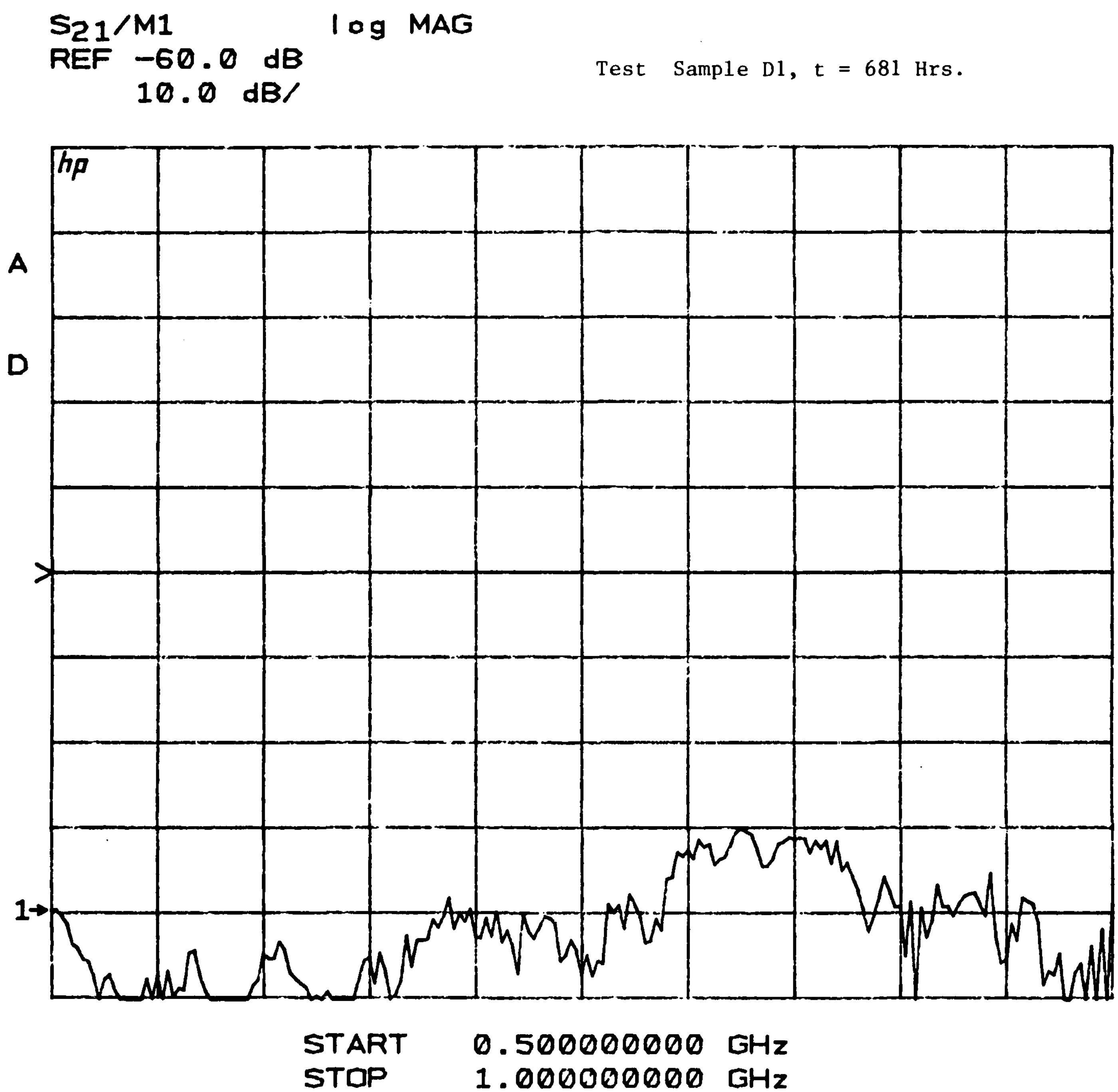

S21/M1 log MAG
REF -60.0 dB
10.0 dB/
Test Sample C2, t = 681 Hrs.
hp
A
D
1
START 0.500000000 GHz
STOP 1.000000000 GHz



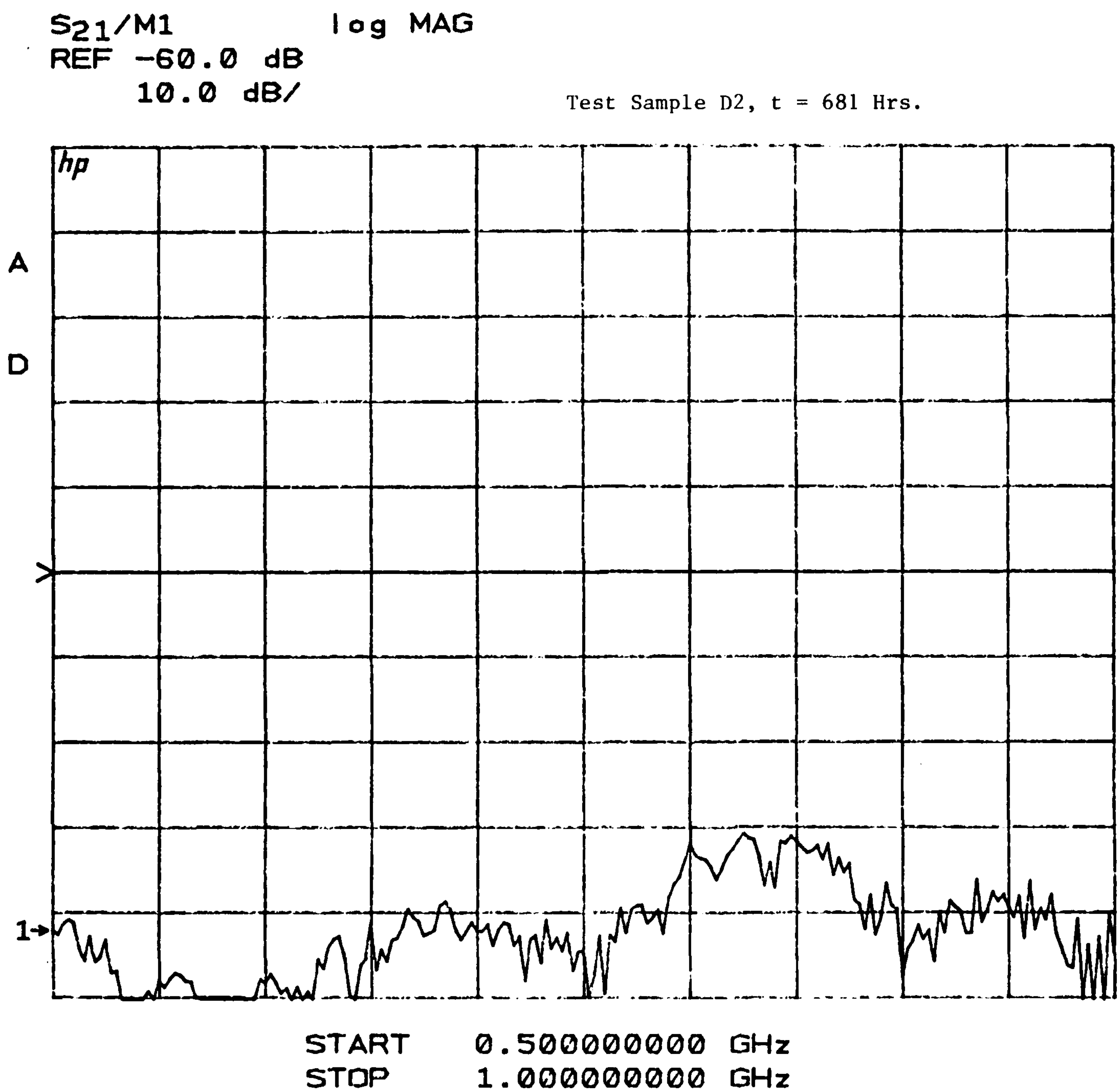
S21/M1 log MAG
REF -60.0 dB
10.0 dB/
Test Sample C3, t = 681 Hrs.
hp
A
D
1
START 0.500000000 GHz
STOP 1.000000000 GHz

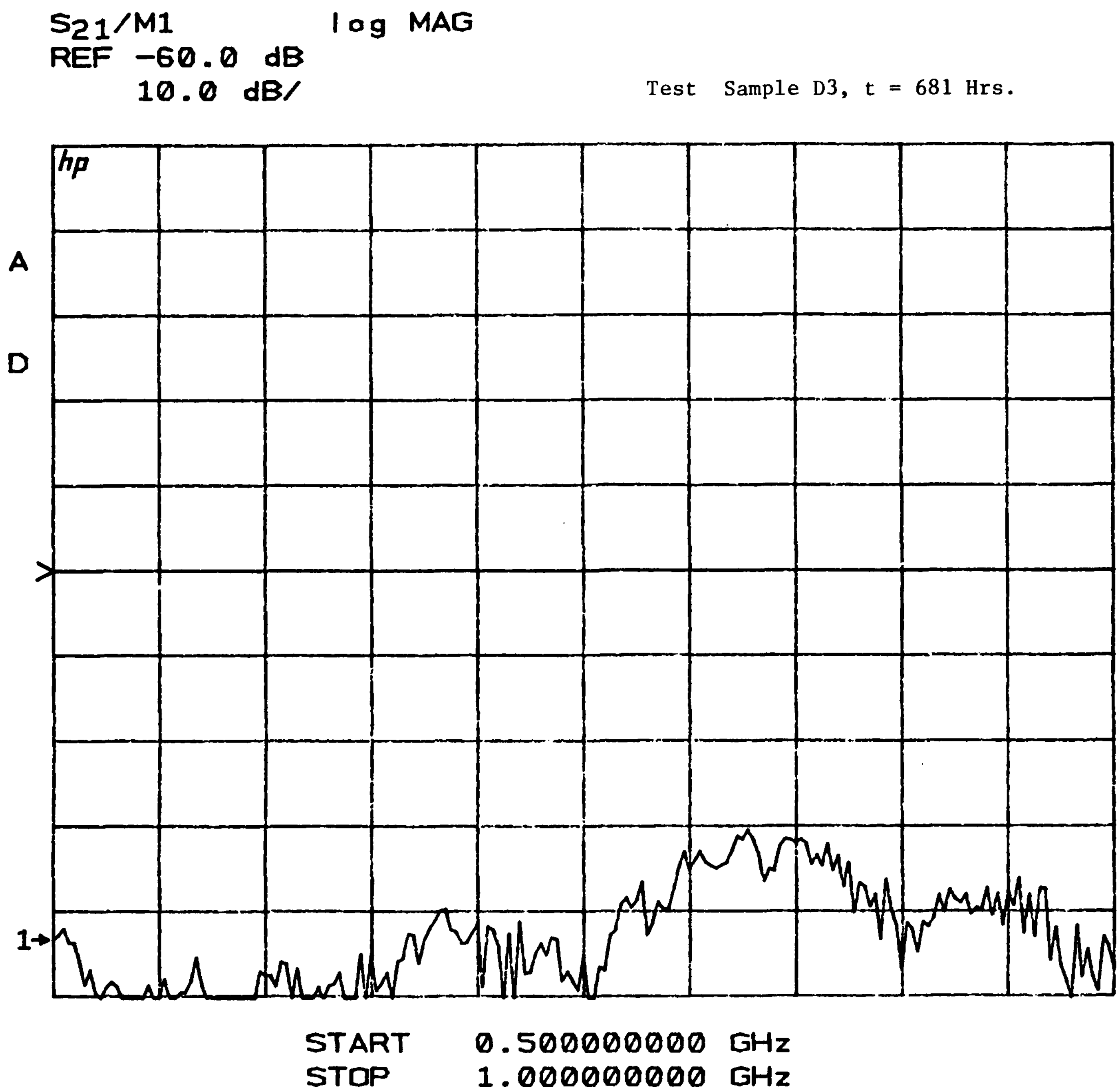
Test Sample C4, t = 681 Hrs.



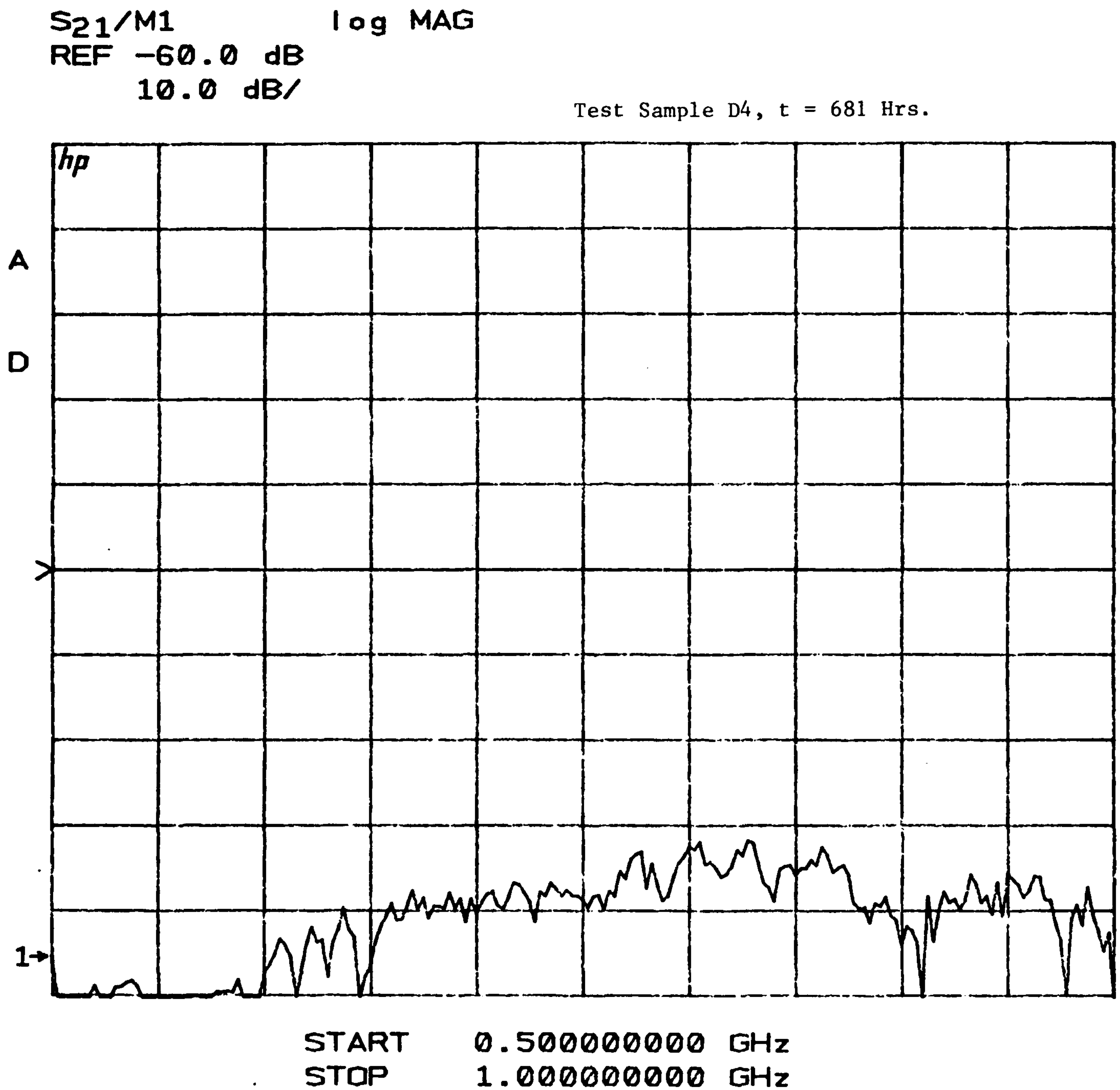


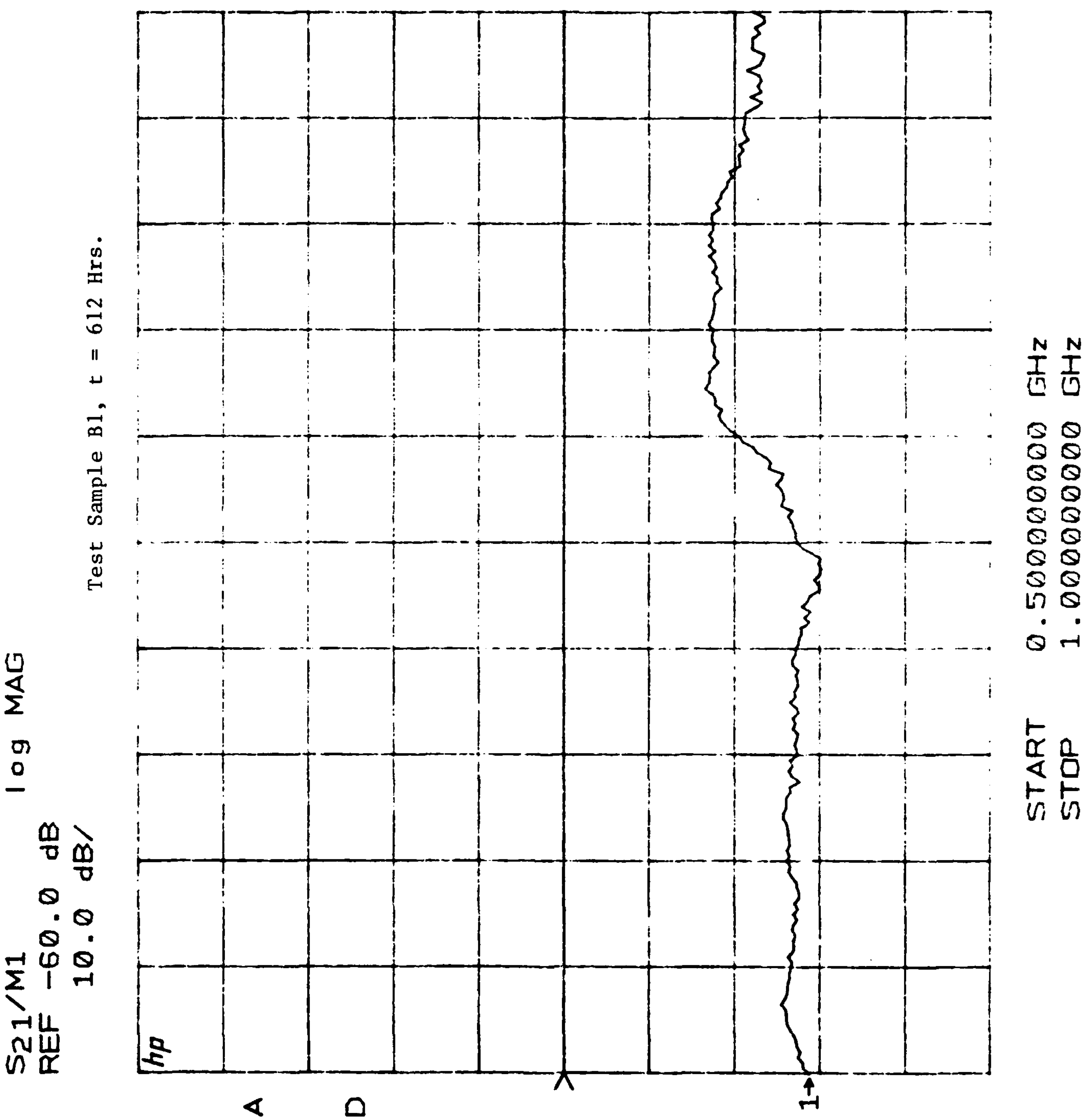
S21/M1
log MAG
REF -60.0 dB
10.0 dB/
Test Sample D1, t = 681 Hrs.
hp
A
D
1
START 0.500000000 GHz
STOP 1.000000000 GHz


S21/M1 log MAG
REF -60.0 dB
10.0 dB/
Test Sample D2, t = 681 Hrs.
hp
A
D
1→
START 0.500000000 GHz
STOP 1.000000000 GHz

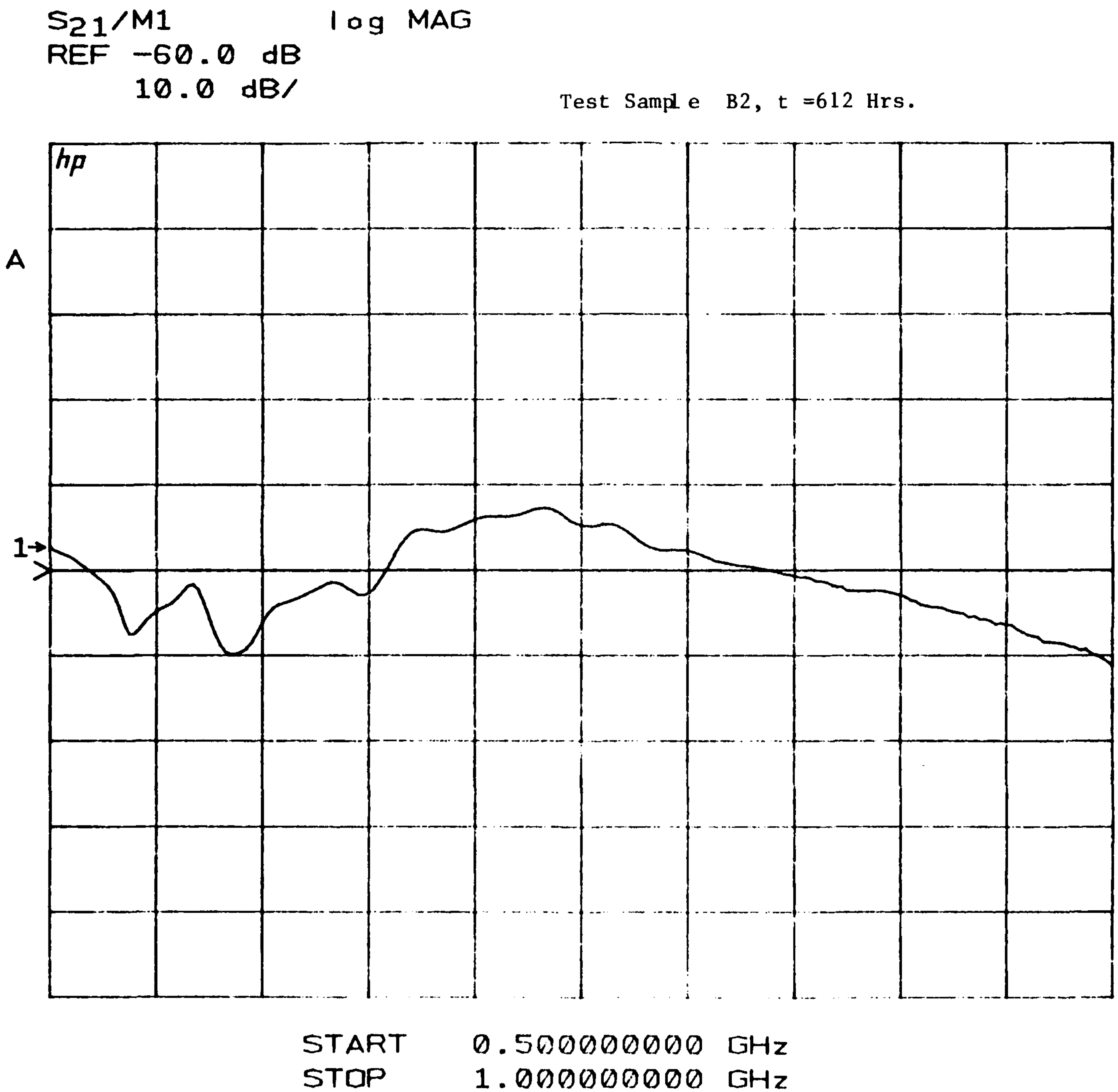

S21/M1
log MAG
REF -60.0 dB
10.0 dB/
Test Sample D3, t = 681 Hrs.
hp
A
D
1
START 0.500000000 GHz
STOP 1.000000000 GHz

Test Sample D4, t = 681 Hrs.

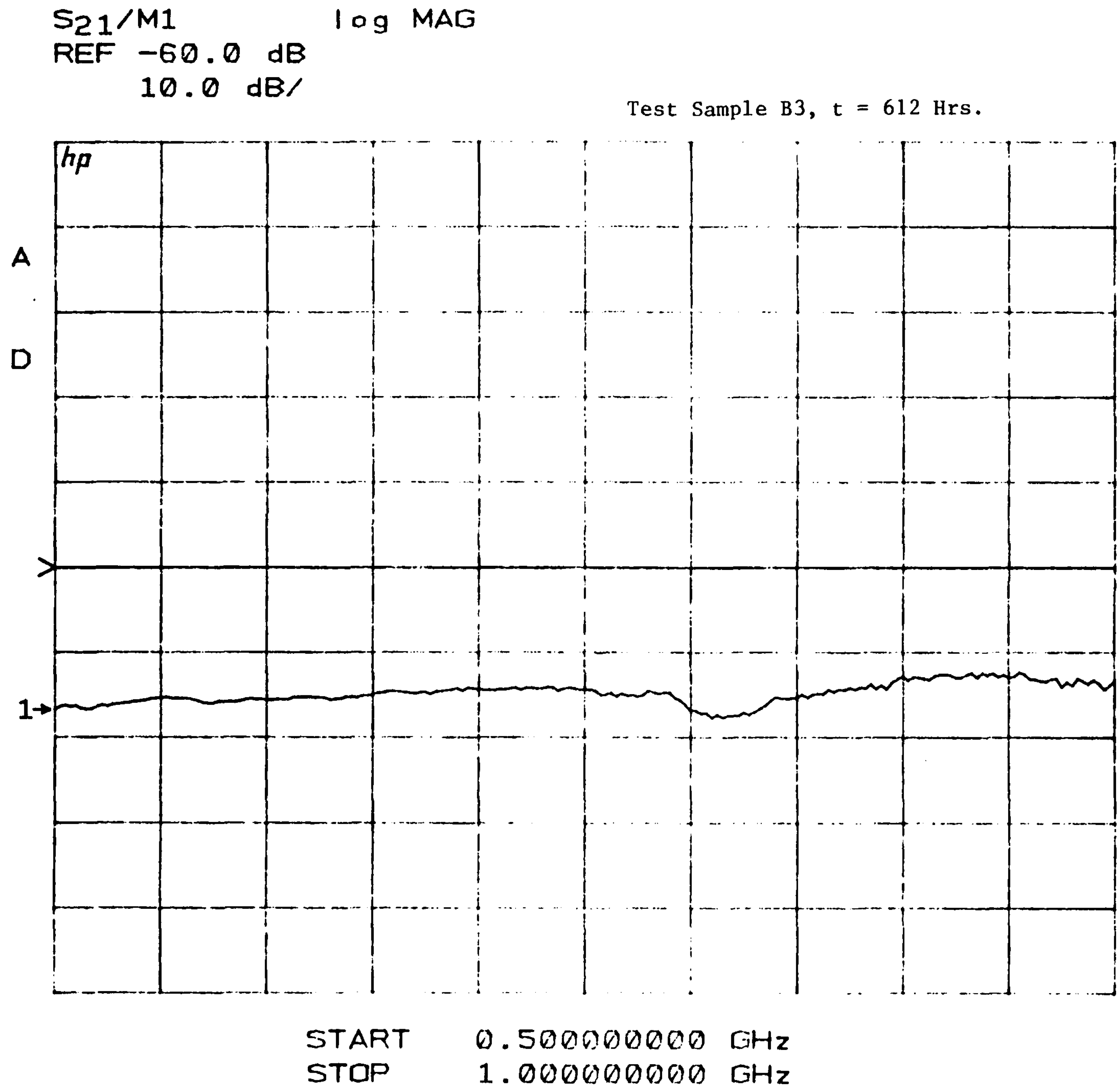




Test Sample B1, t = 612 Hrs.

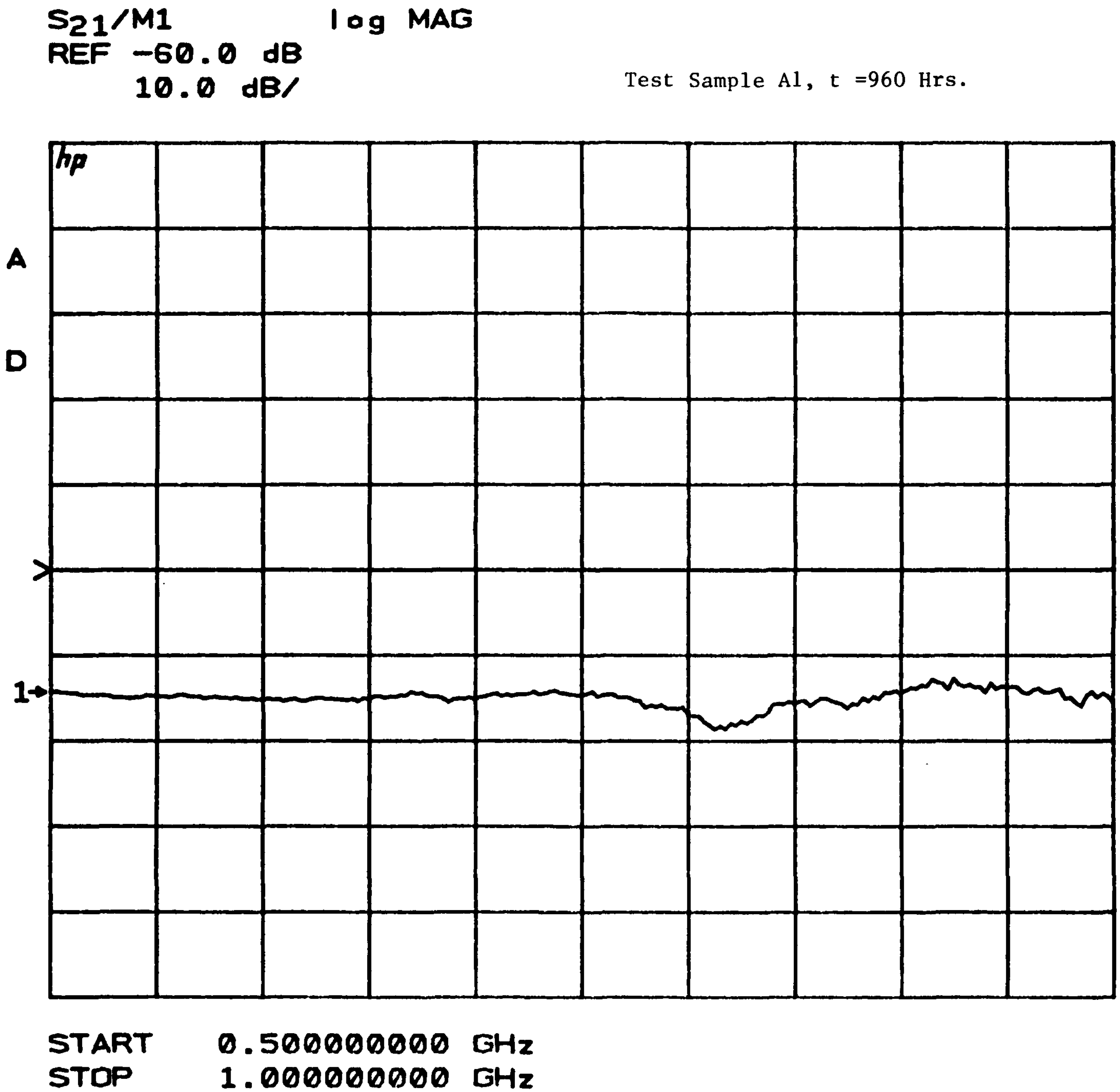


S21/M1 log MAG
REF -60.0 dB
10.0 dB/
Test Sample B2, t =612 Hrs.
hp
A
1
START 0.500000000 GHz
STOP 1.000000000 GHz

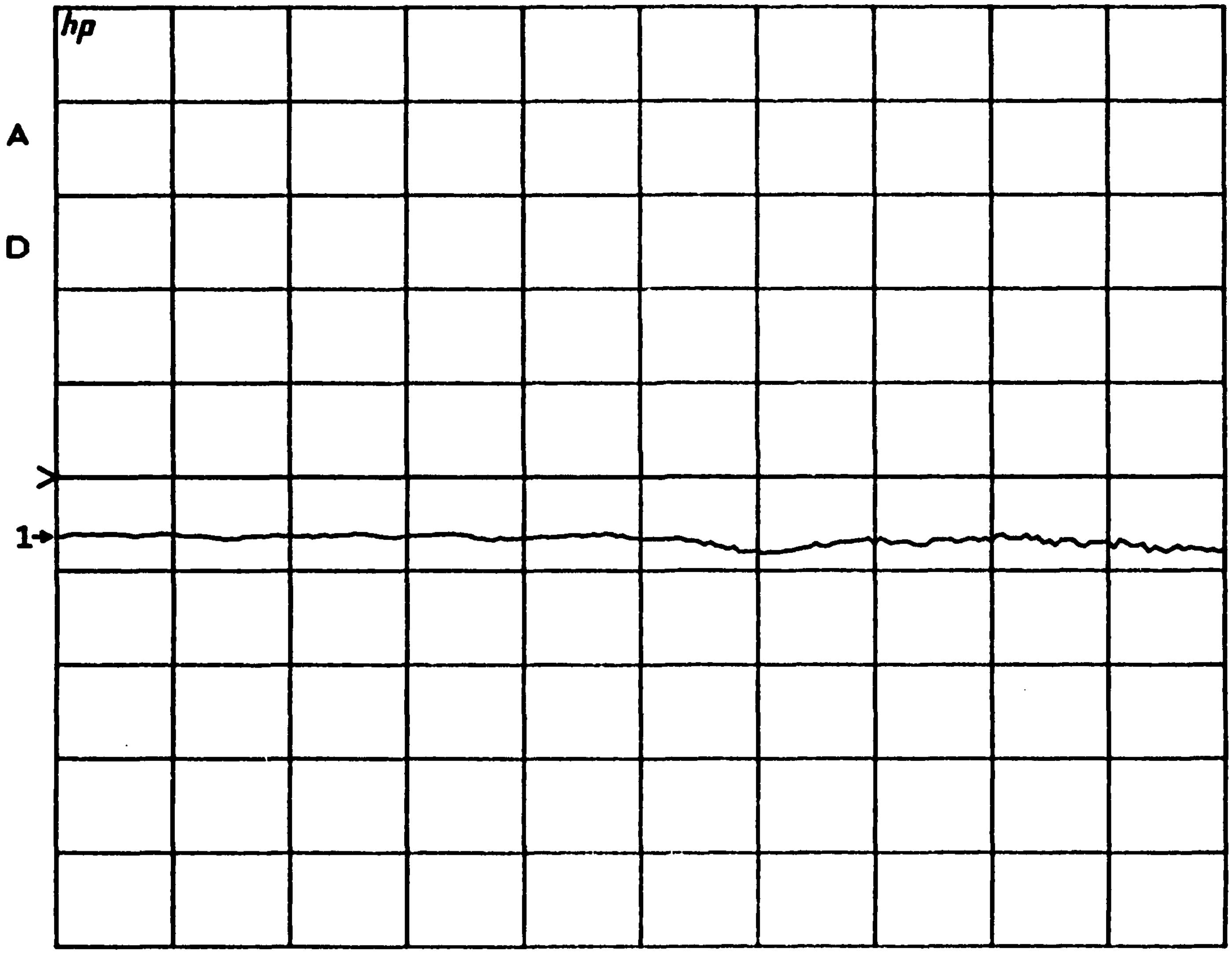


S21/M1 log MAG
REF -60.0 dB
10.0 dB/
Test Sample B3, t = 612 Hrs.
hp
A
D
1
START 0.500000000 GHz
STOP 1.000000000 GHz

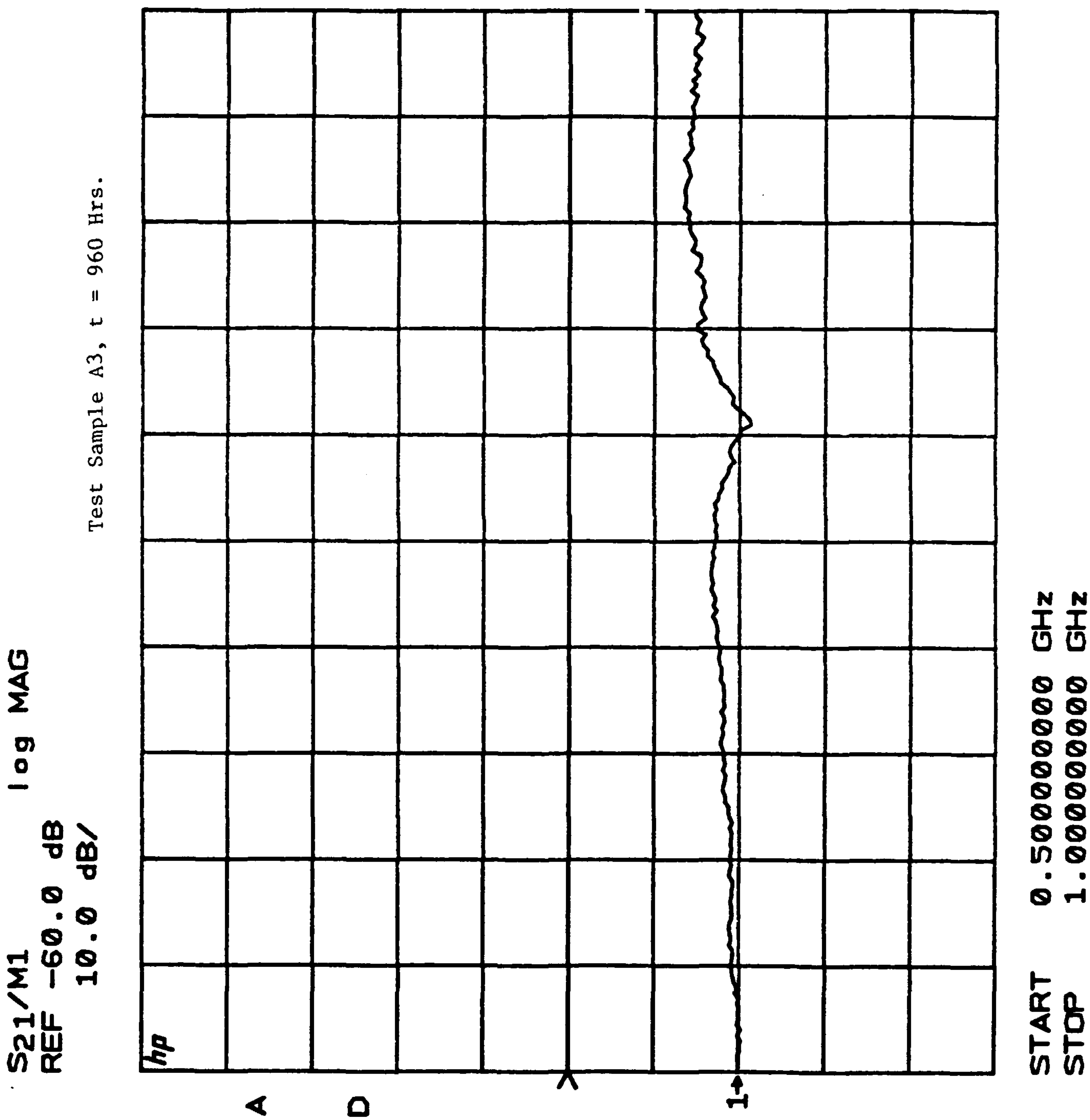
Test Sample Al, t =960 Hrs.



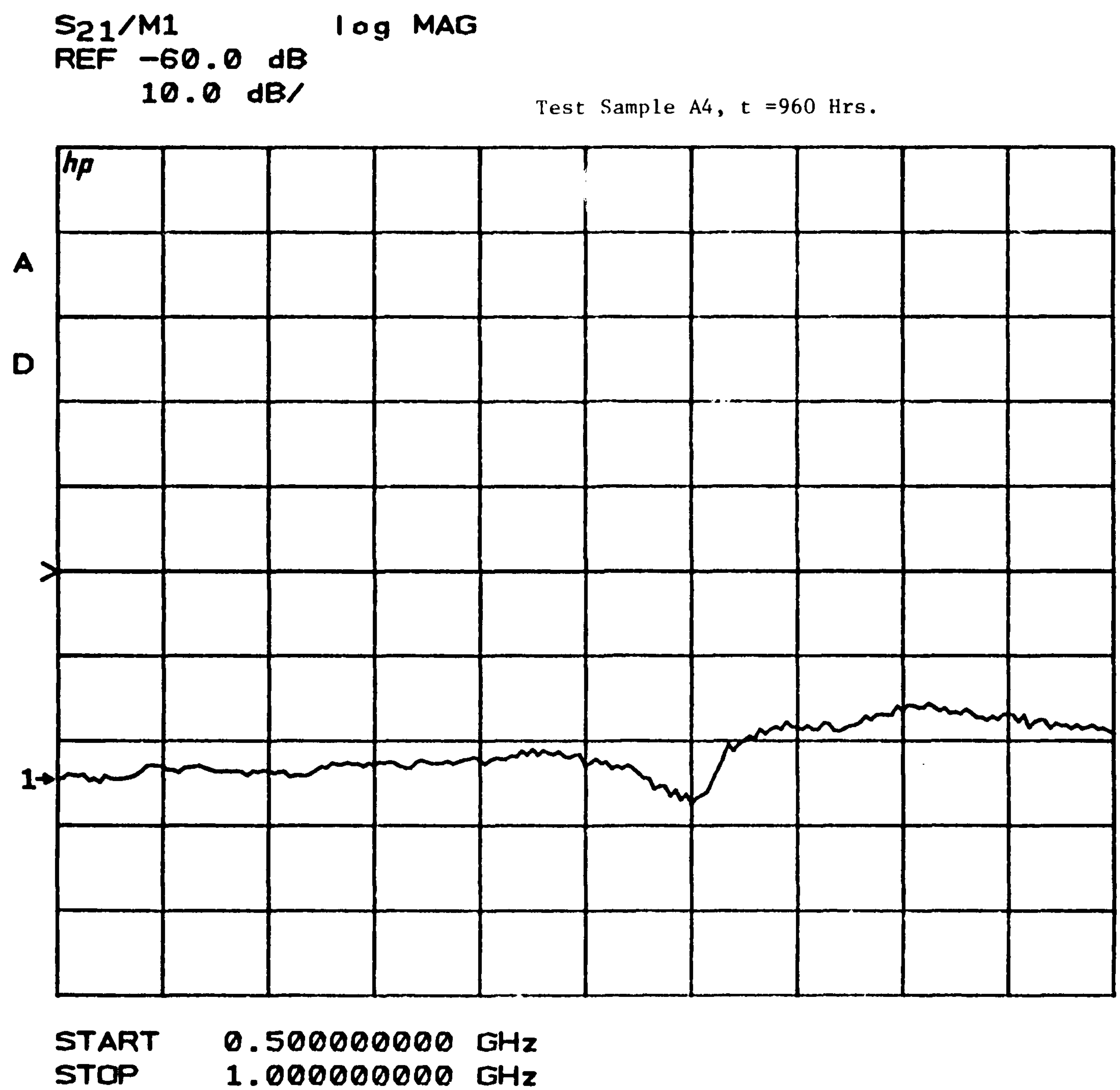
Test Sample A2, t =960 Hrs.

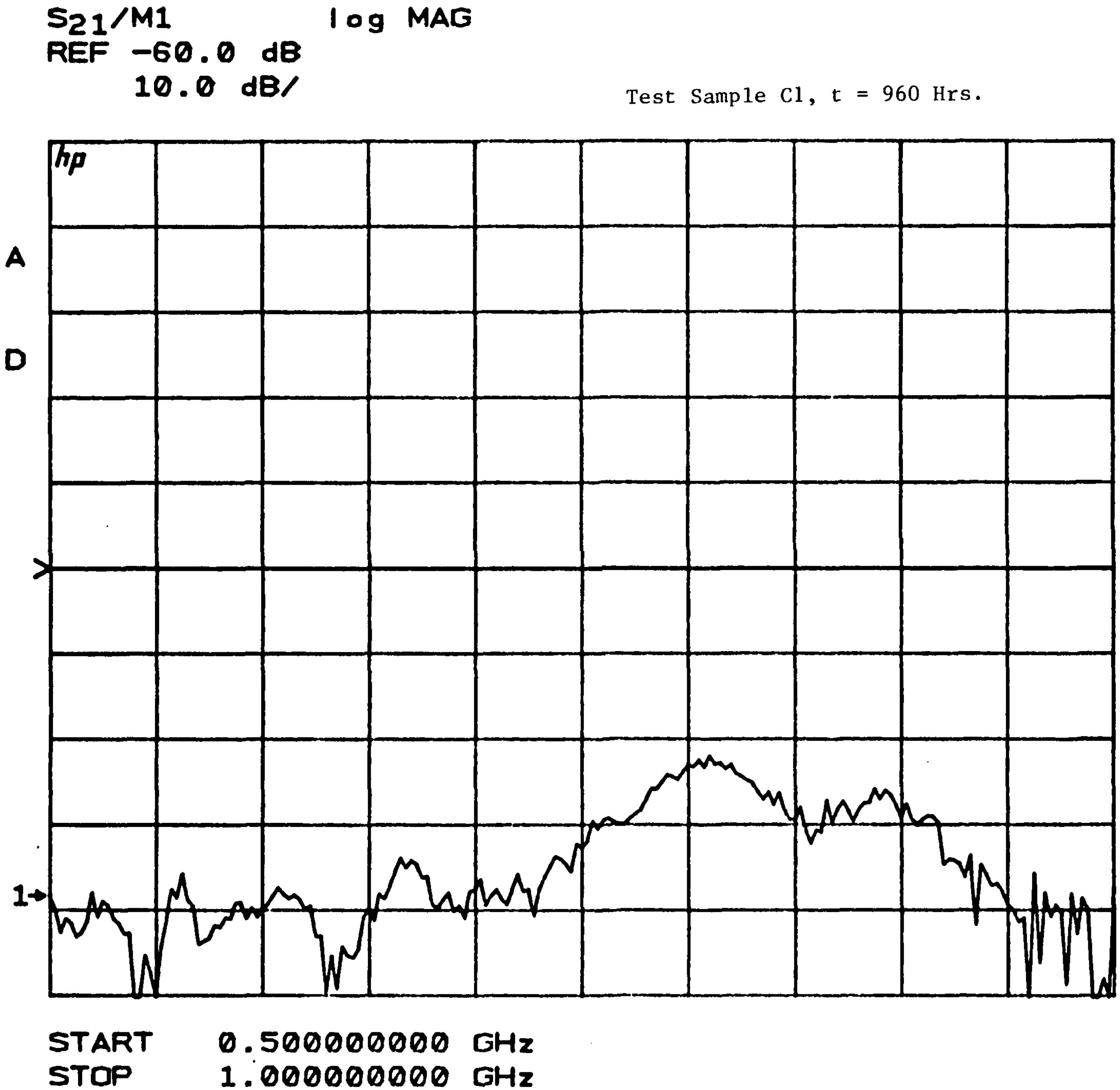


START 0.500000000 GHz
STOP 1.000000000 GHz



Test Sample A3, t = 960 Hrs.

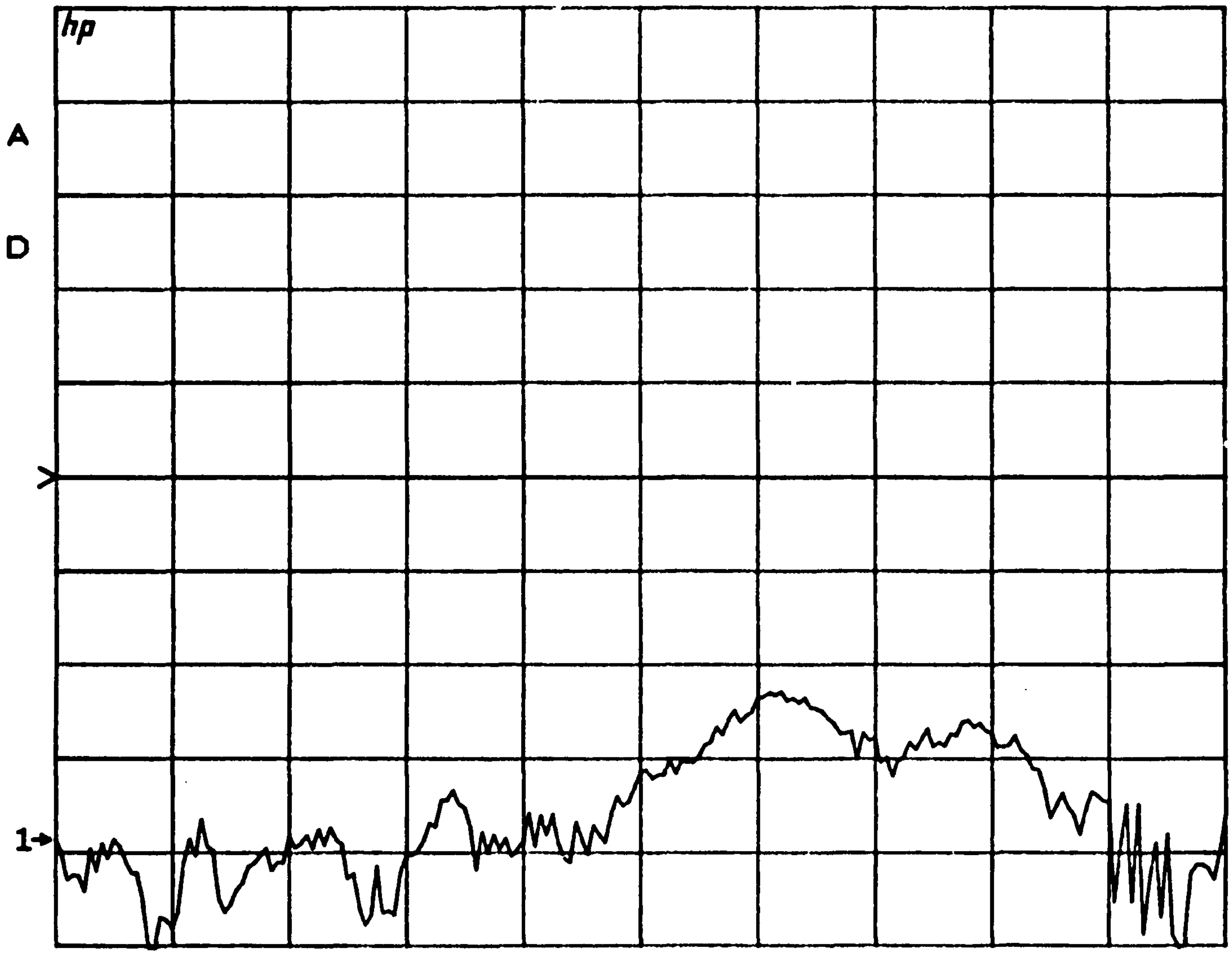

S21/M1 log MAG
REF -60.0 dB
10.0 dB/
Test Sample A4, t =960 Hrs.
hp
A
D
1
START 0.500000000 GHz
STOP 1.000000000 GHz



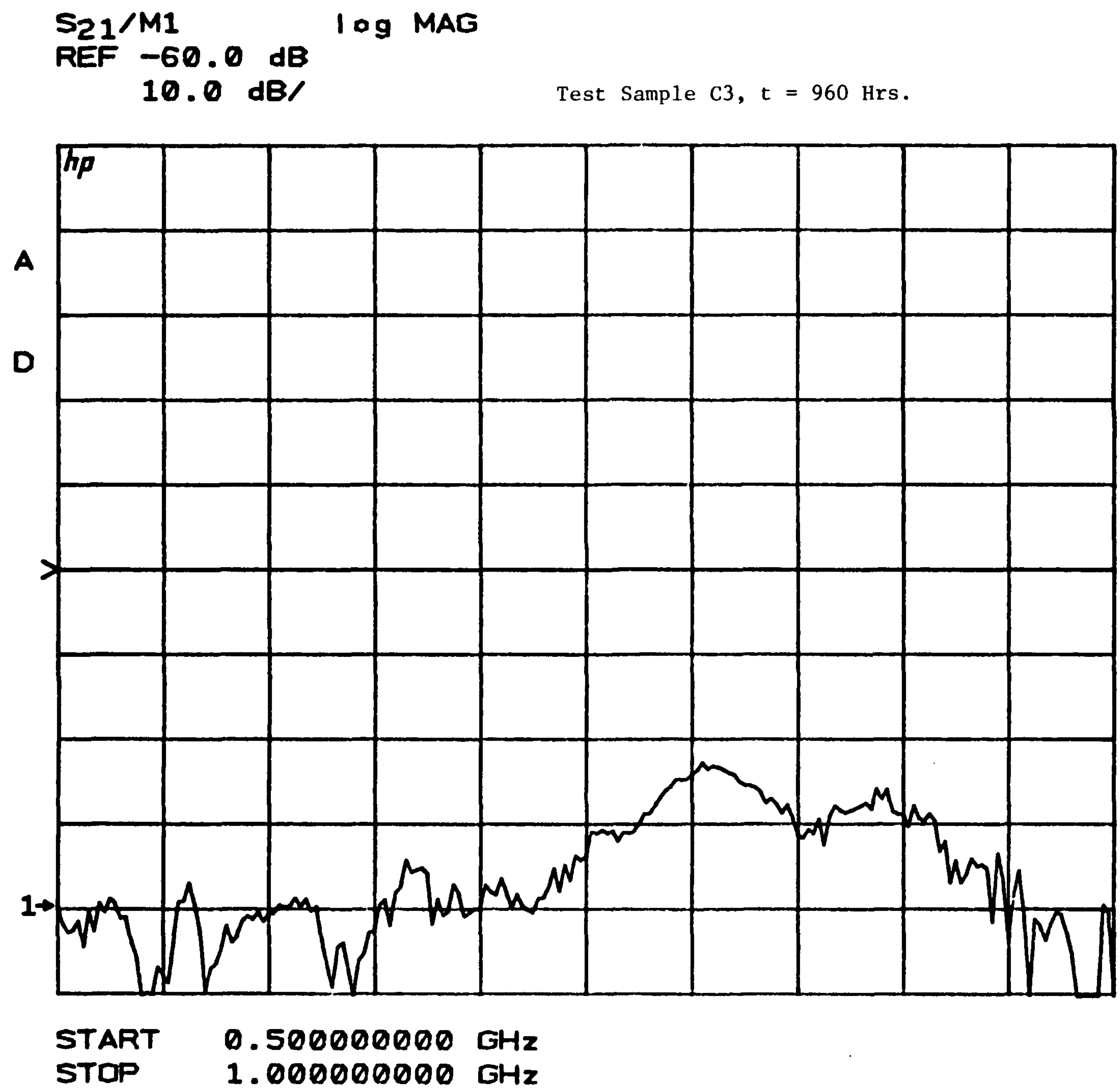
S21/M1 log MAG
REF -60.0 dB
10.0 dB/
Test Sample Cl, t = 960 Hrs.
hp
A
D
1
START 0.500000000 GHz
STOP 1.000000000 GHz

S_{21}/M1 log MAG
REF -60.0 dB
10.0 dB/

Test Sample C2, t = 960 Hrs.



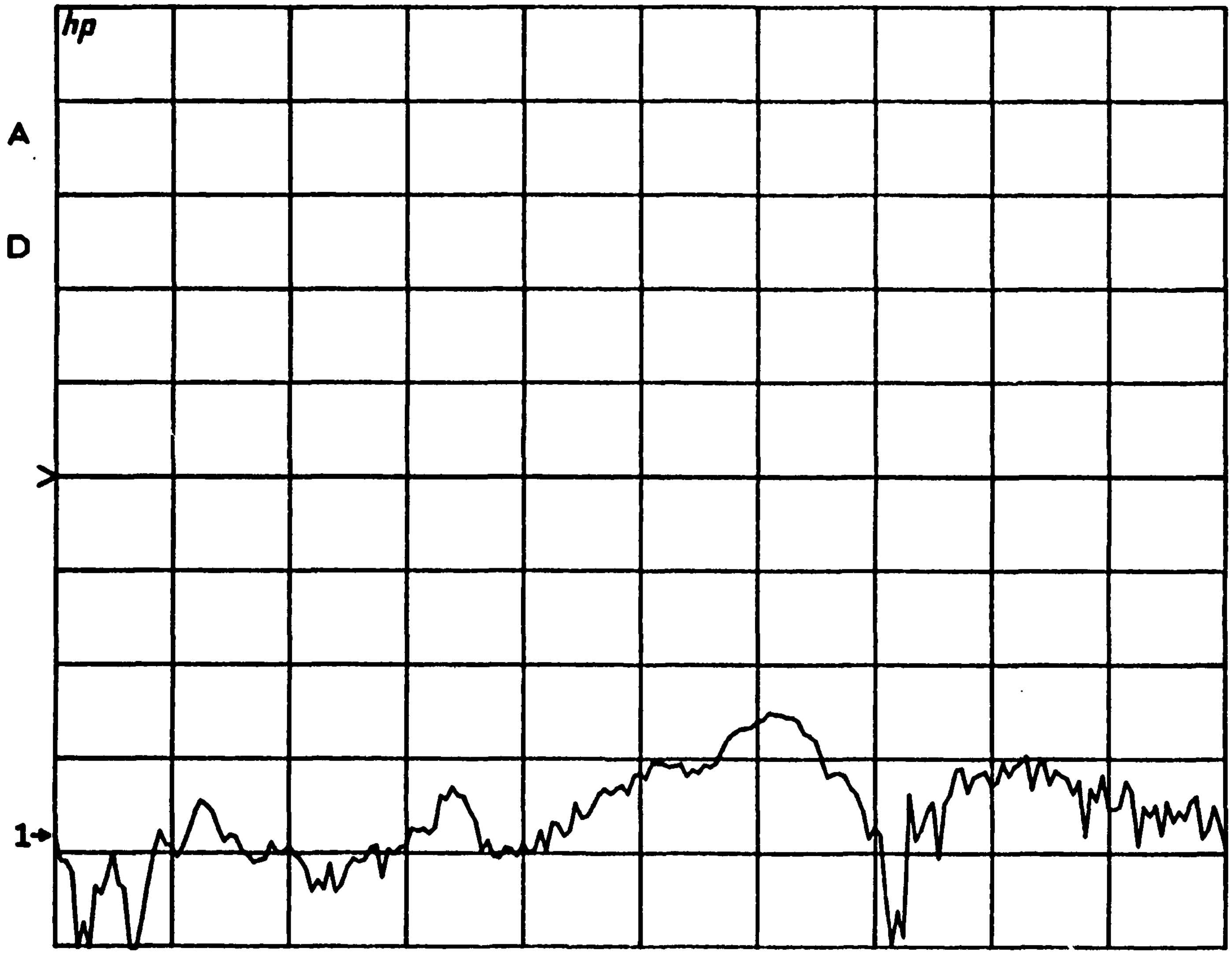
START 0.500000000 GHz
STOP 1.000000000 GHz



S_{21}/M1 log MAG
REF -60.0 dB
10.0 dB/
Test Sample C3, t = 960 Hrs.
hp
A
D
1→
START 0.500000000 GHz
STOP 1.000000000 GHz

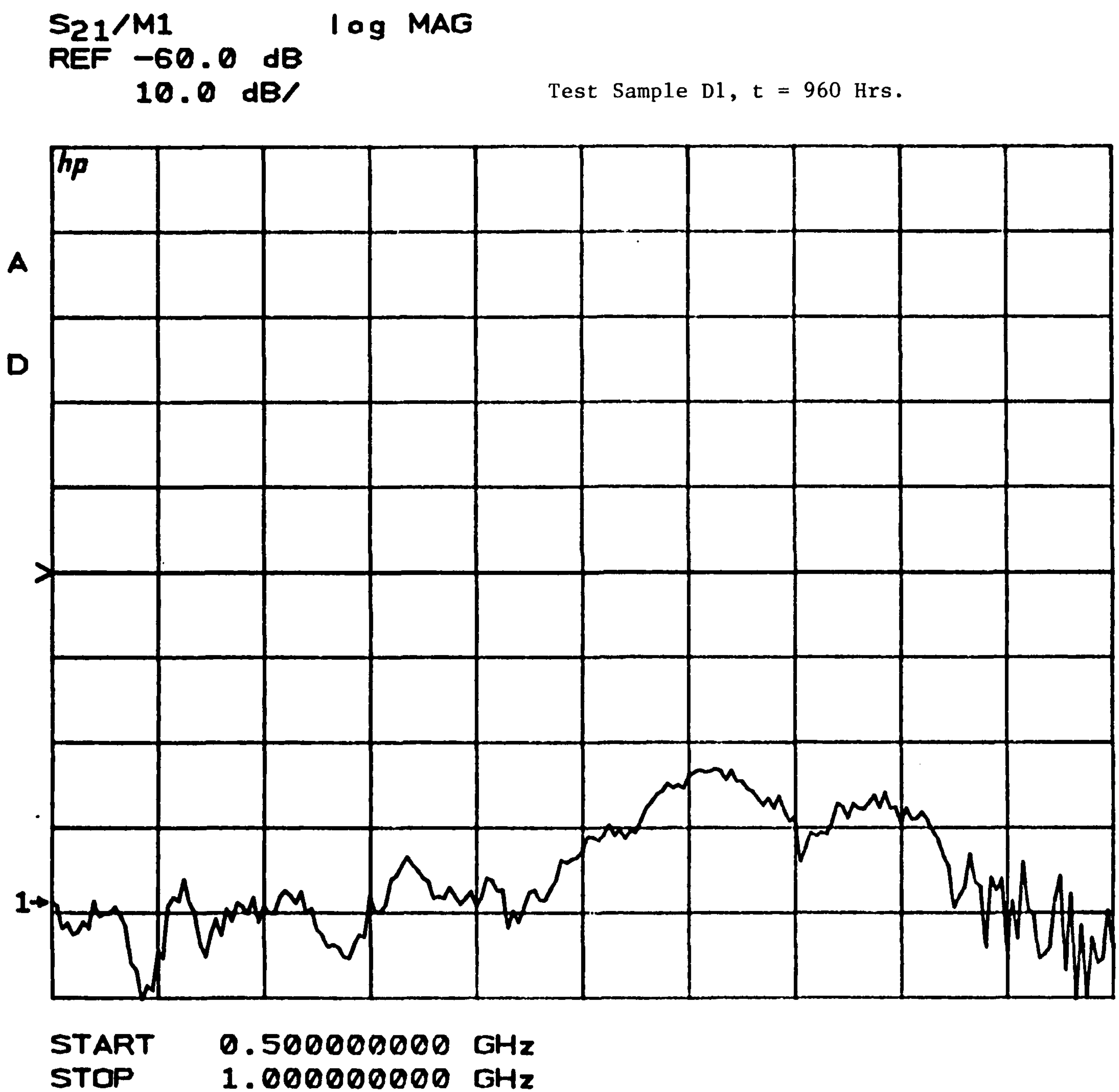
S_{21}/M1 log MAG
REF -60.0 dB
10.0 dB/

Test Sample C4, t = 960 Hrs.



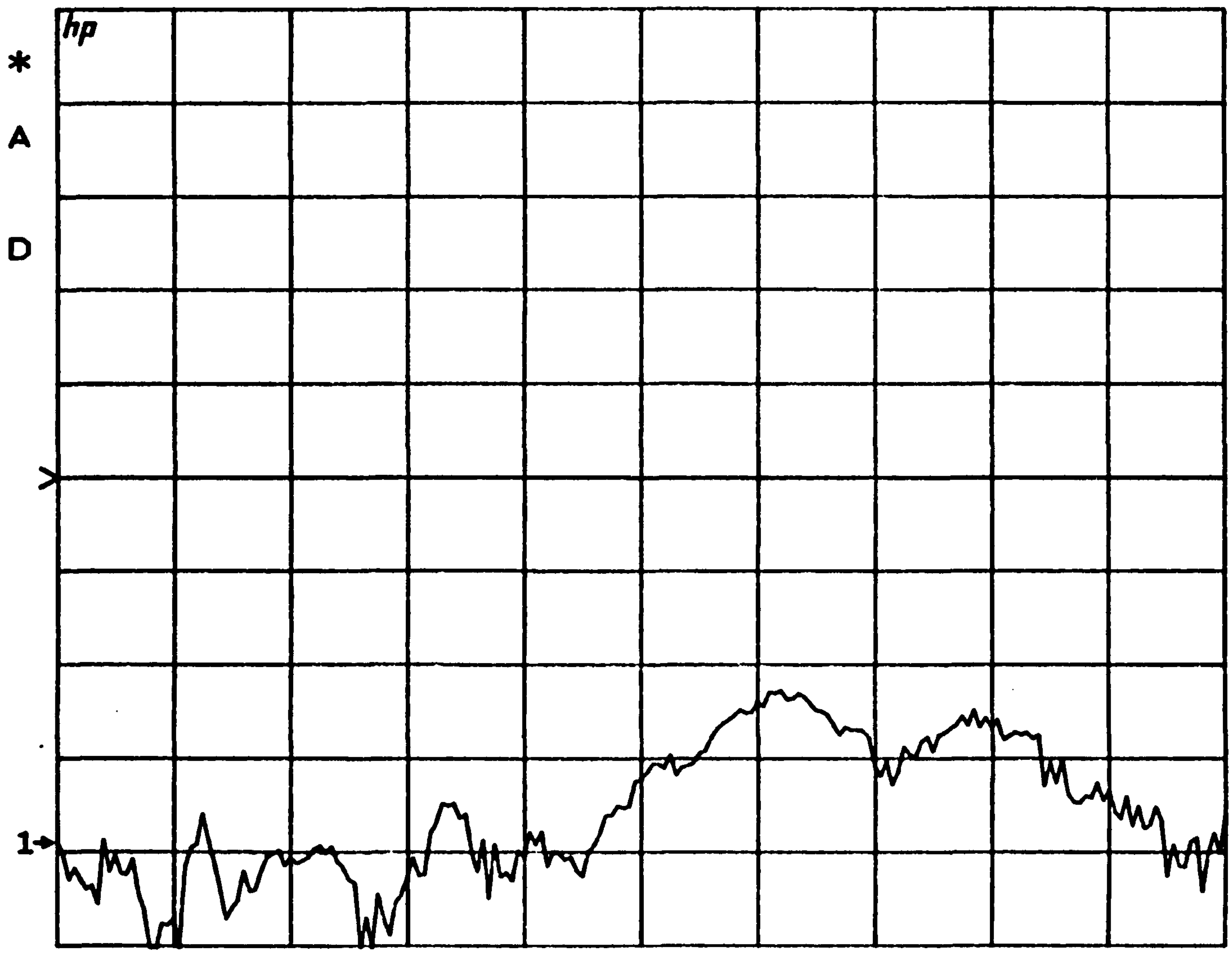
START 0.500000000 GHz
STOP 1.000000000 GHz

Test Sample D1, t = 960 Hrs.



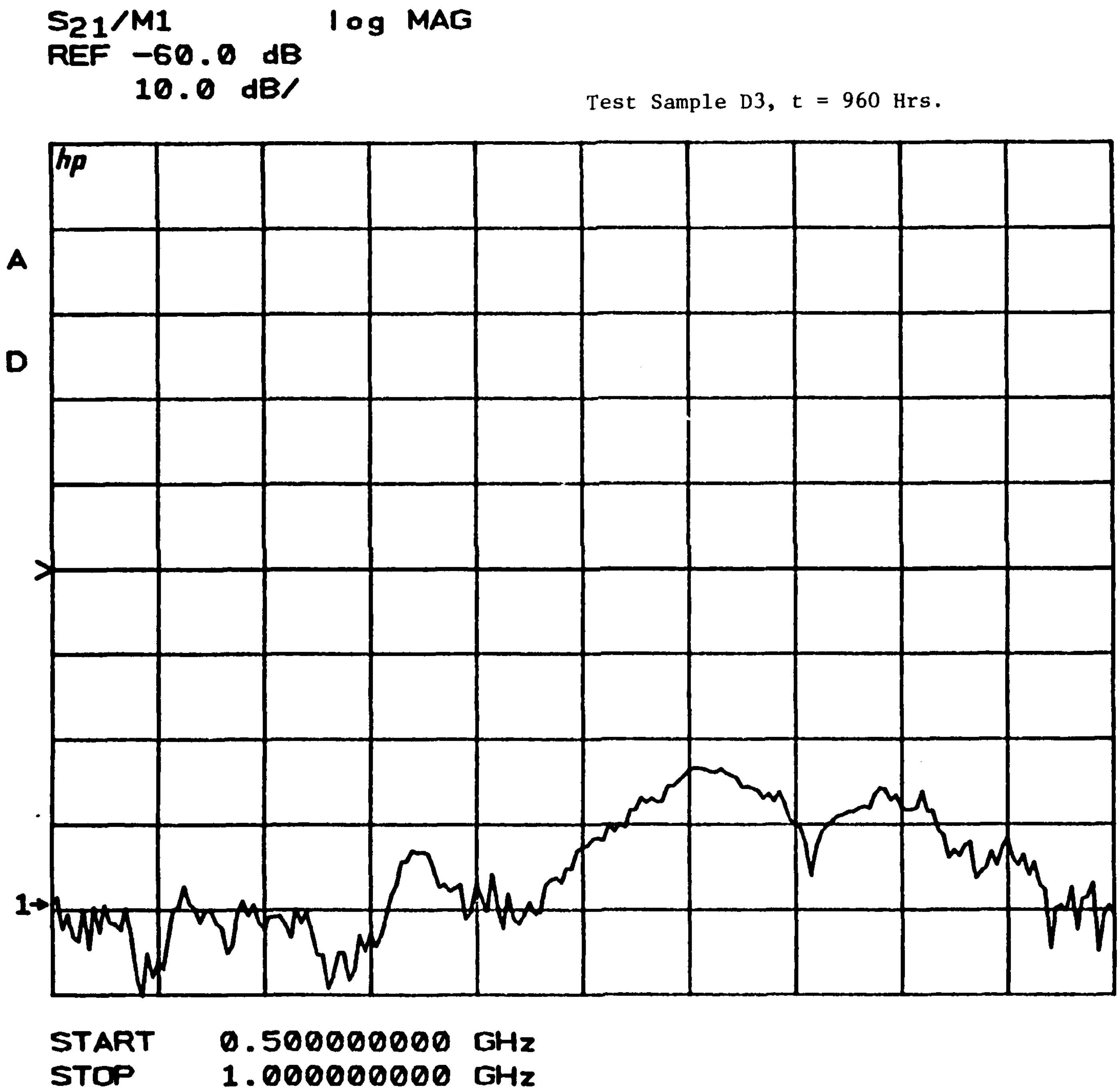
S21/M1 log MAG
REF -60.0 dB
10.0 dB/

Test Sample D2, t=960 Hrs.

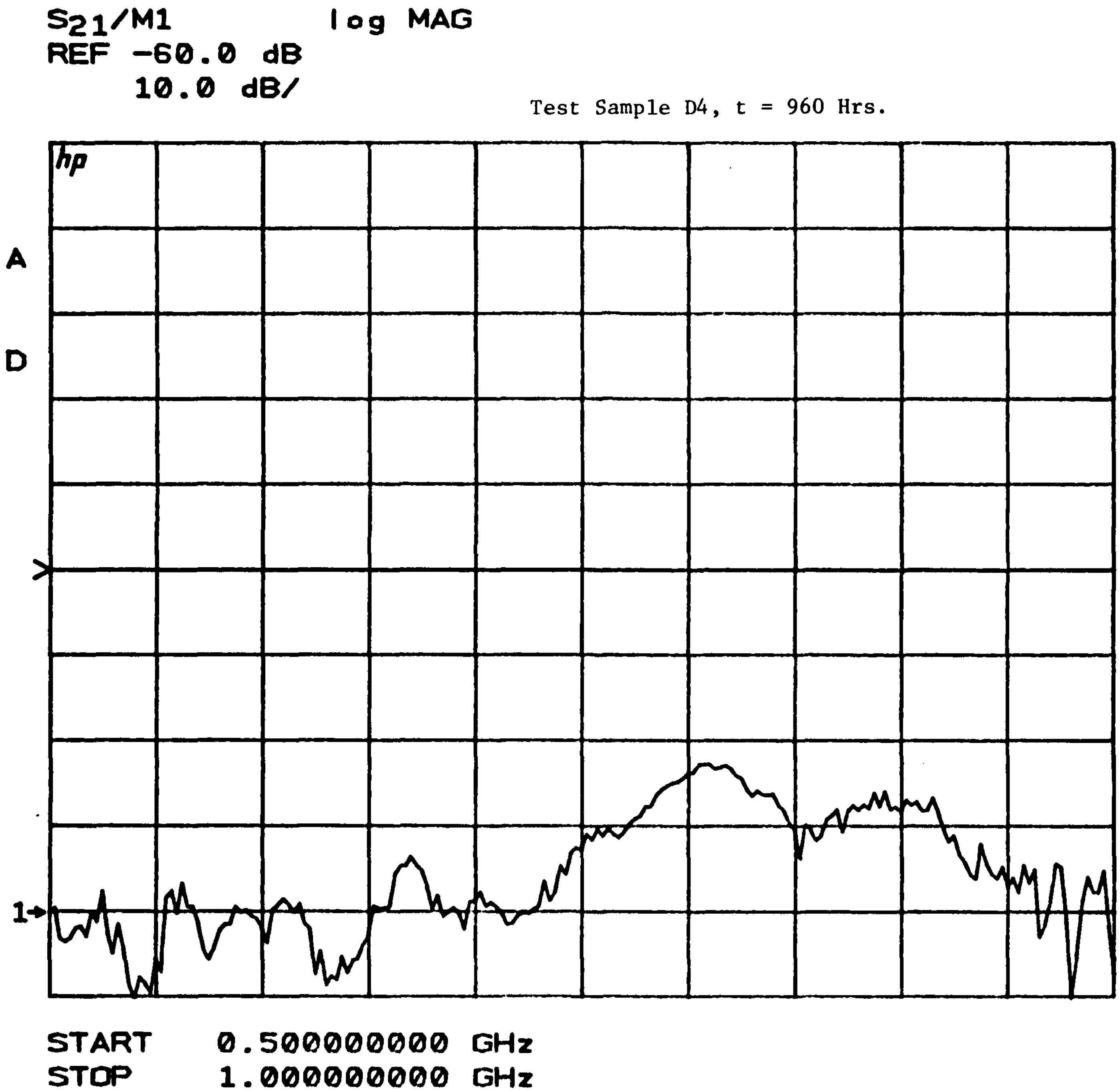


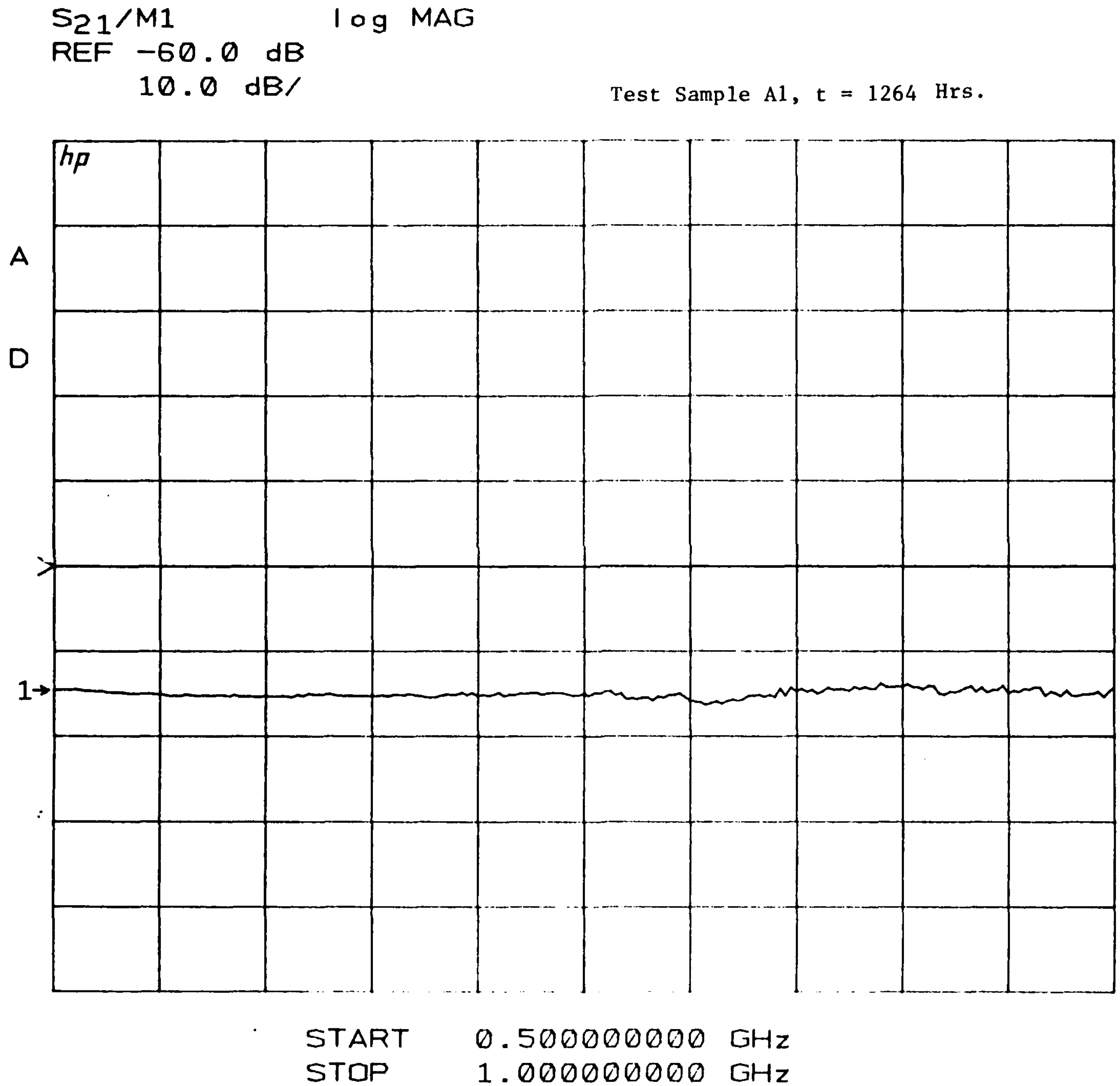
START 0.500000000 GHz
STOP 1.000000000 GHz

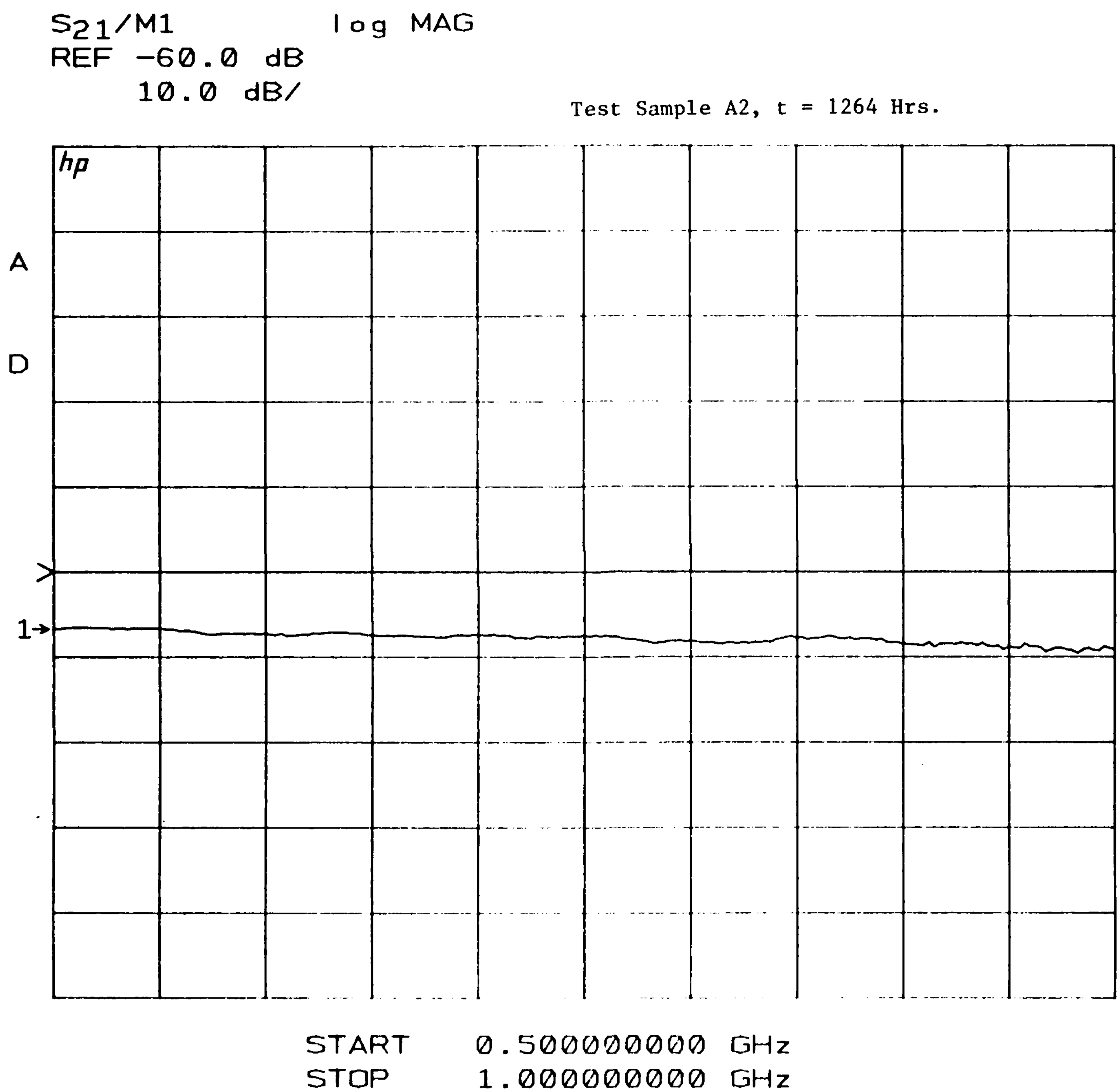
Test Sample D3, t = 960 Hrs.

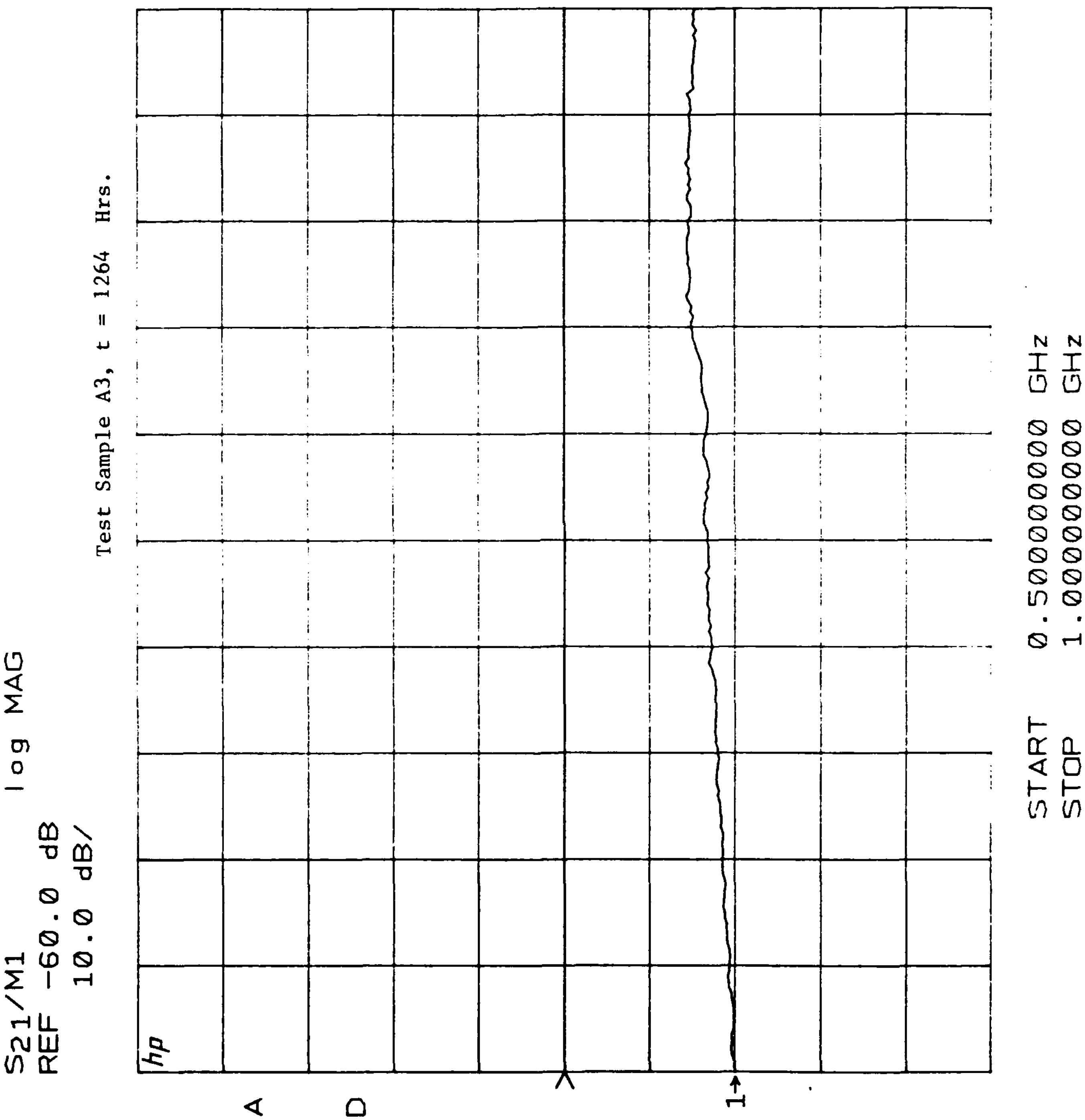


Test Sample D4, t = 960 Hrs.

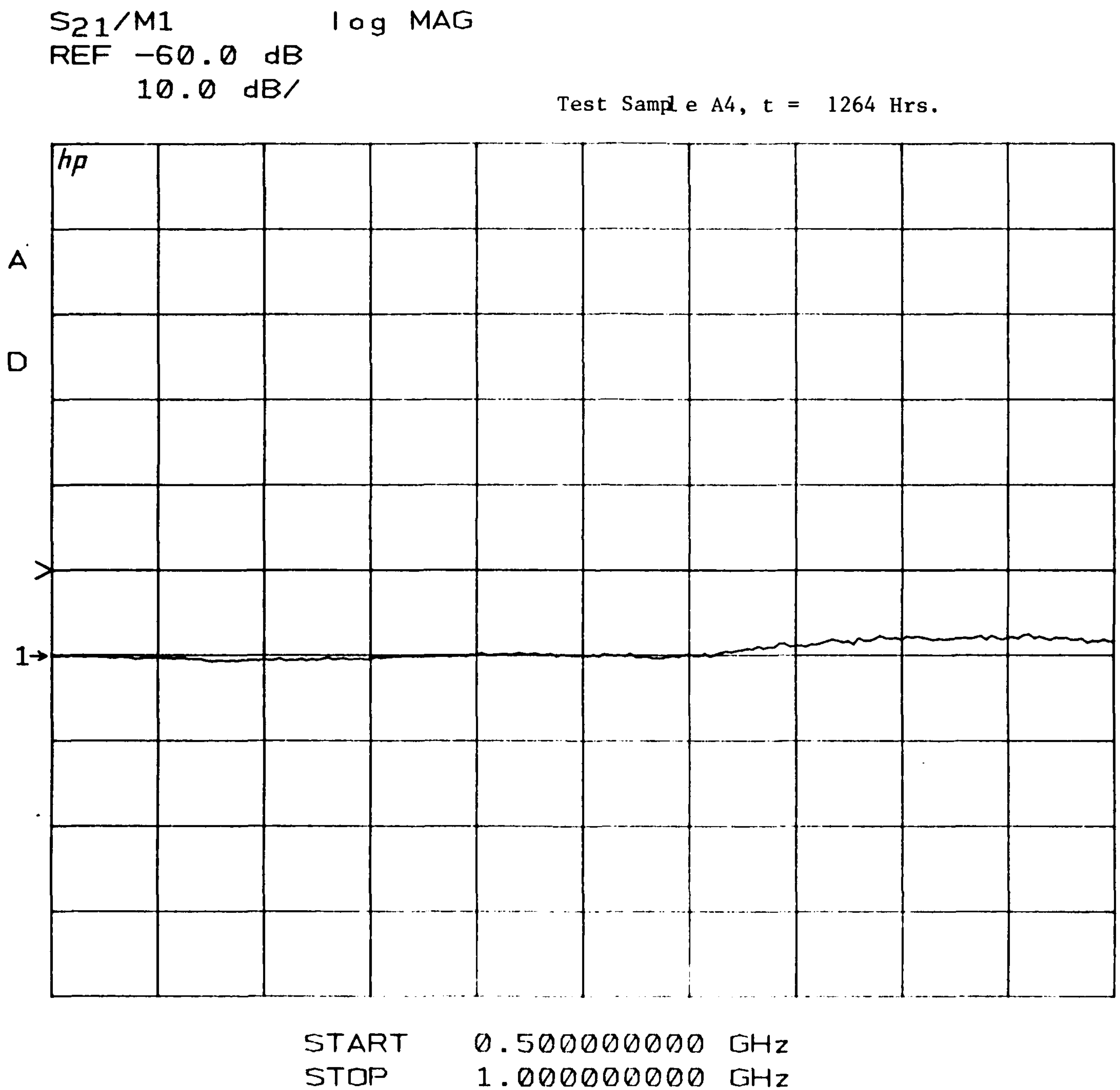



S21/M1
log MAG
REF -60.0 dB
10.0 dB/
Test Sample A1, t = 1264 Hrs.
hp
A
D
1
START 0.500000000 GHz
STOP 1.000000000 GHz

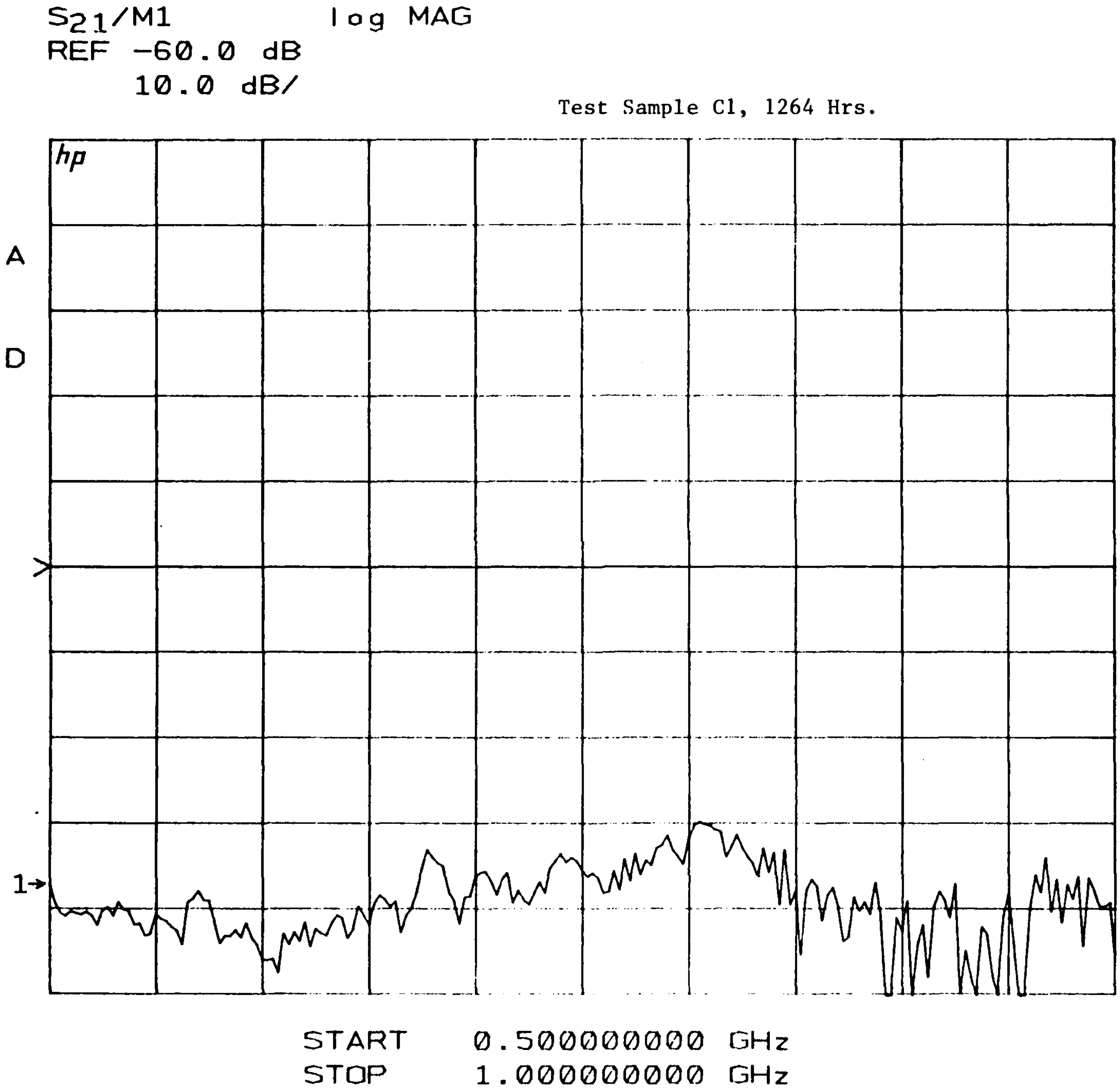

S21/M1 log MAG
REF -60.0 dB
10.0 dB/
Test Sample A2, t = 1264 Hrs.
hp
A
D
1
START 0.500000000 GHz
STOP 1.000000000 GHz

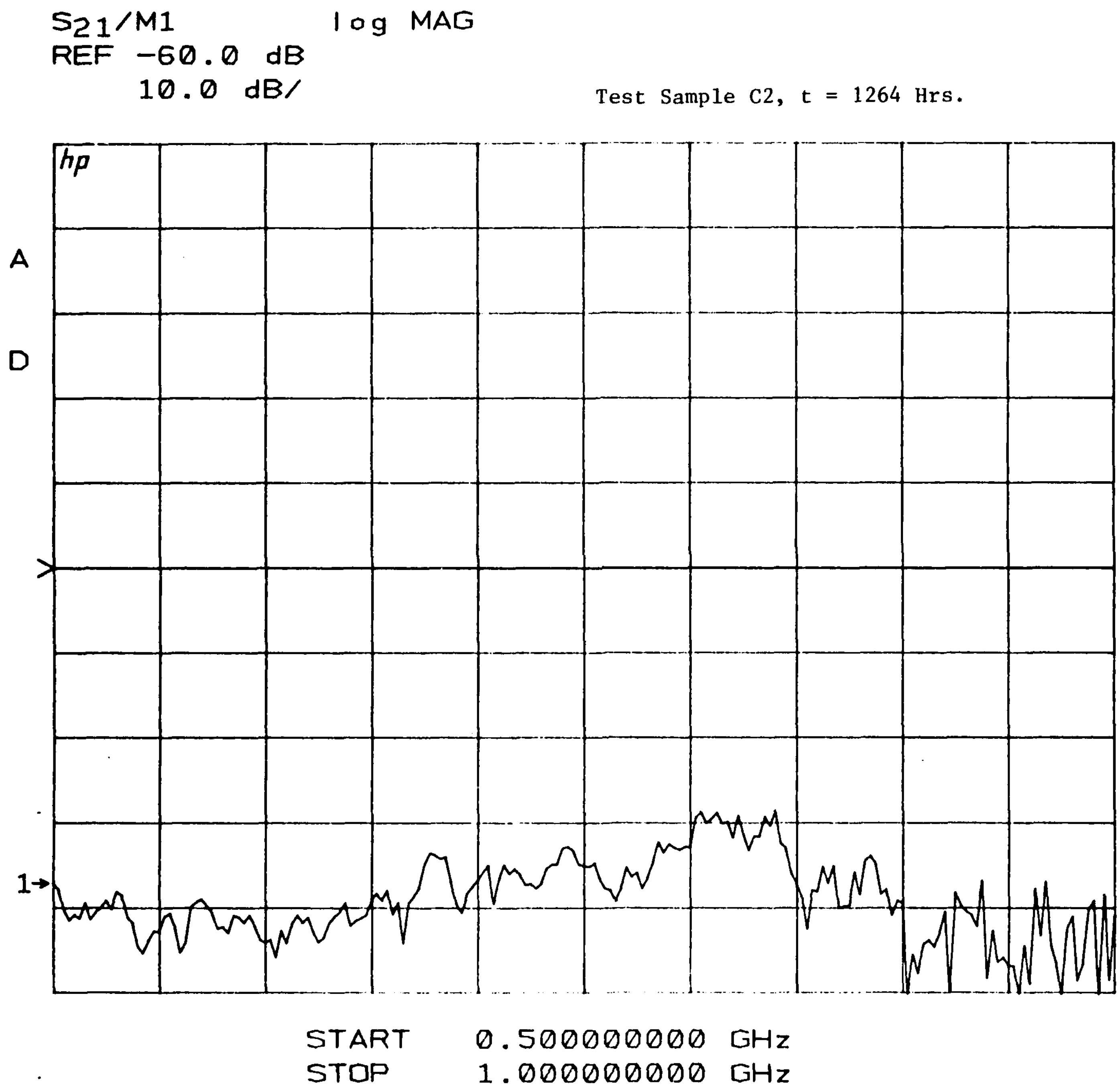


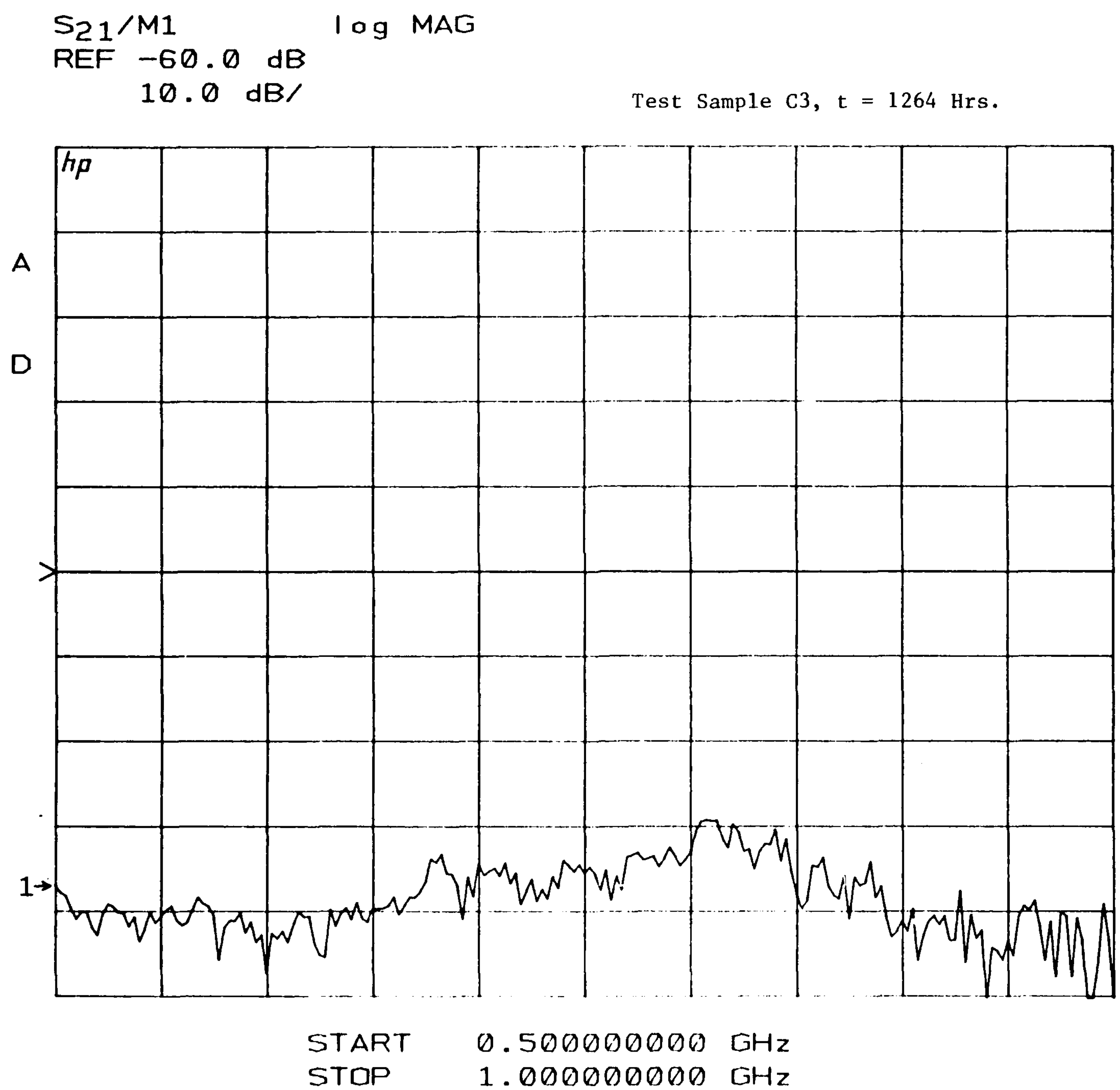
Test Sample A3, t = 1264 Hrs.
S21/M1 log MAG
REF -60.0 dB
10.0 dB/
hp
START 0.500000000 GHz
STOP 1.000000000 GHz



S21/M1 log MAG
REF -60.0 dB
10.0 dB/
Test Sampl e A4, t = 1264 Hrs.
hp
A
D
1
START 0.500000000 GHz
STOP 1.000000000 GHz

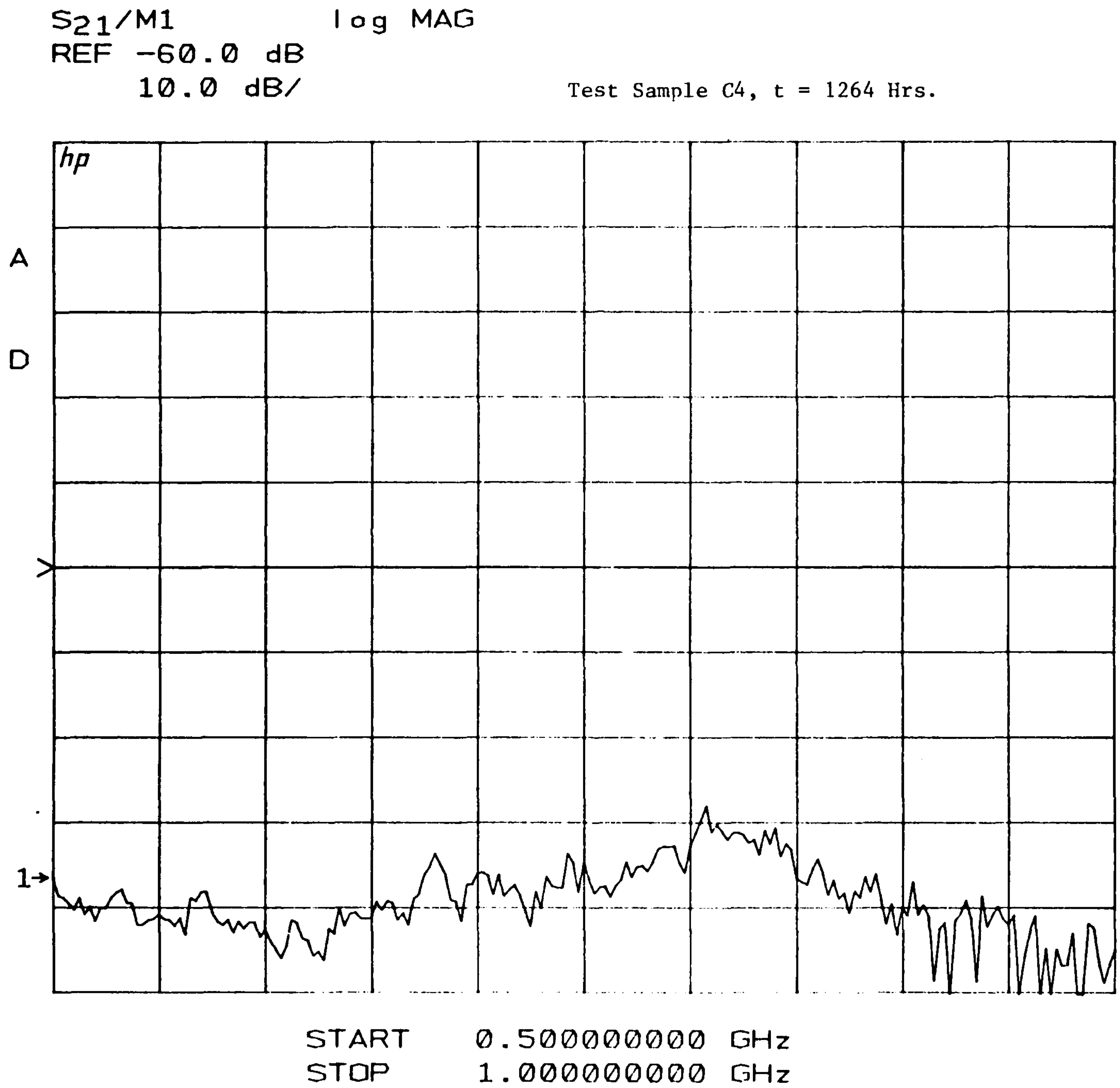

S21/M1
log MAG
REF -60.0 dB
10.0 dB/
Test Sample Cl, 1264 Hrs.
hp
A
D
1→
START 0.500000000 GHz
STOP 1.000000000 GHz

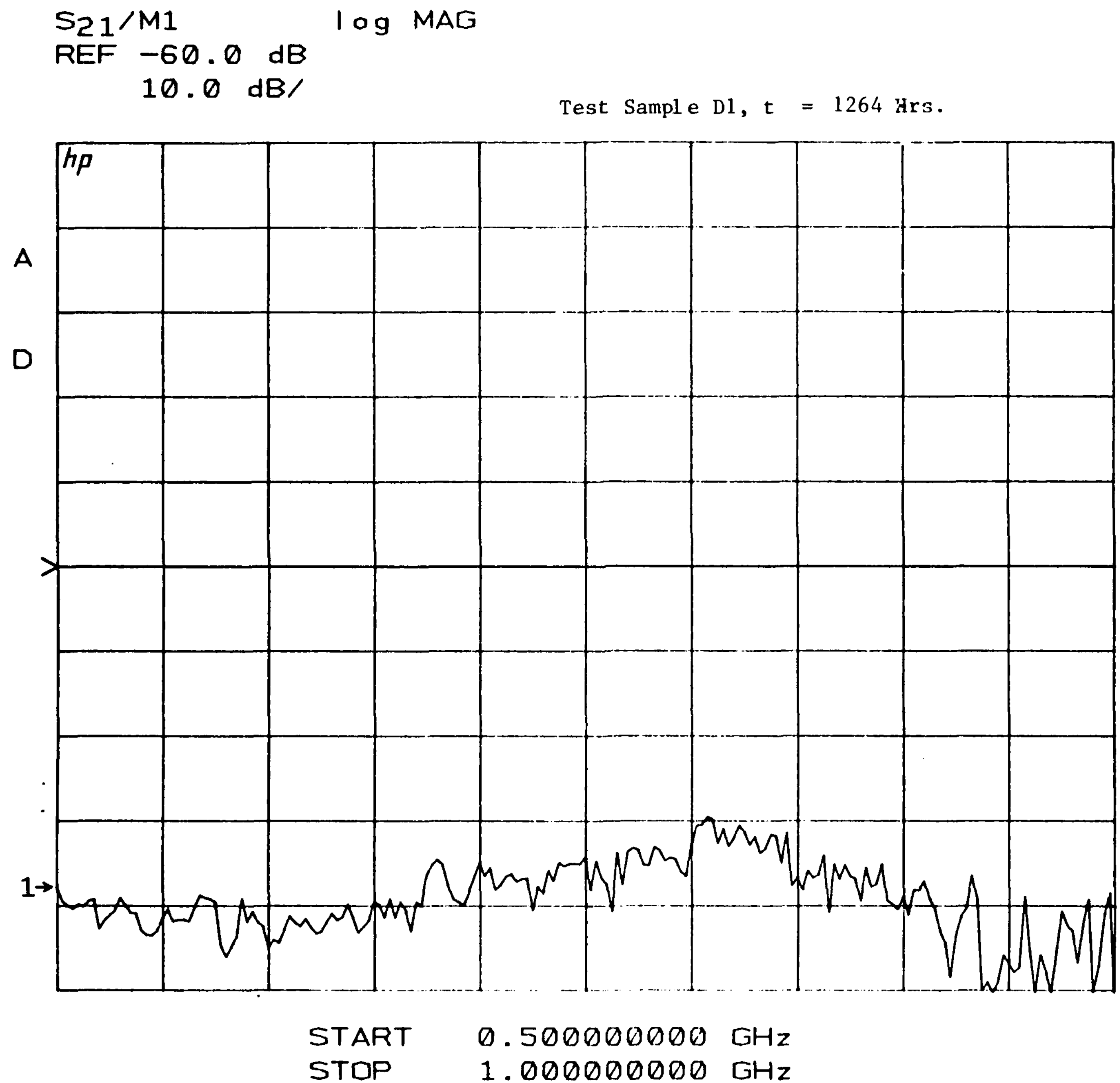

S21/M1 log MAG
REF -60.0 dB
10.0 dB/
Test Sample C2, t = 1264 Hrs.
hp
A
D
1
START 0.500000000 GHz
STOP 1.000000000 GHz



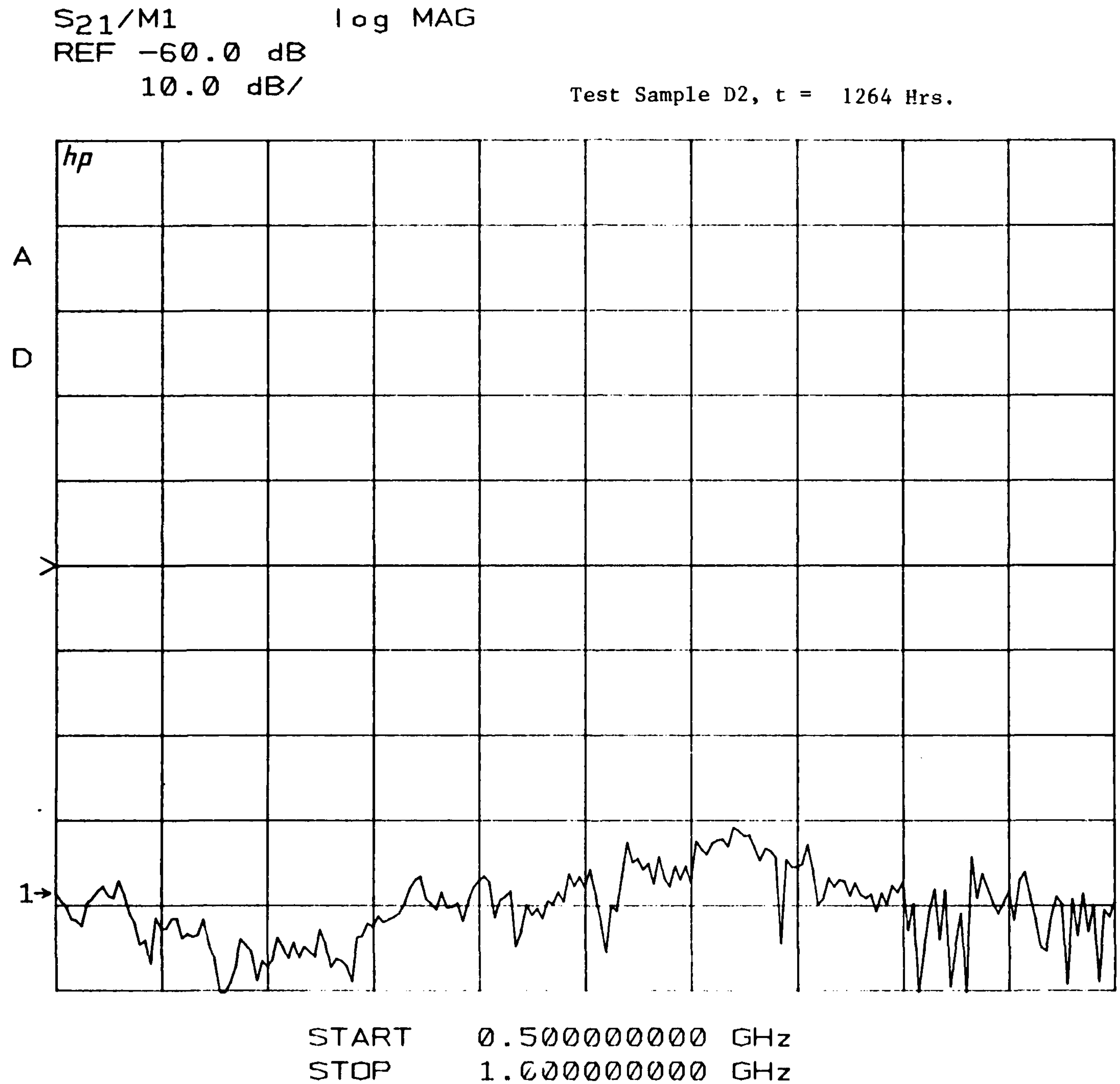
S_{21}/M1 log MAG
REF -60.0 dB
10.0 dB/
Test Sample C3, t = 1264 Hrs.
hp
A
D
1→
START 0.500000000 GHz
STOP 1.000000000 GHz

Test Sample C4, t = 1264 Hrs.

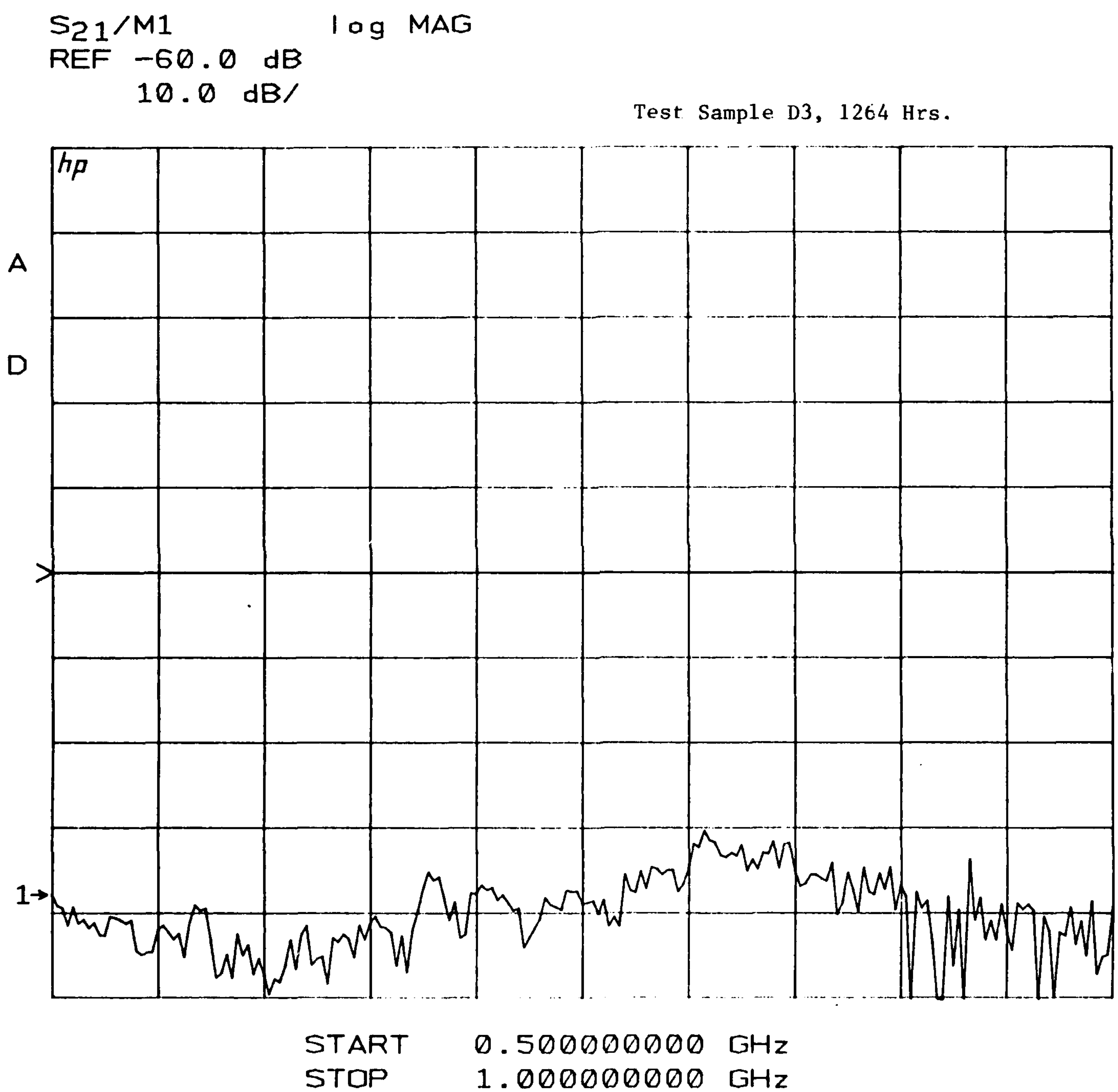


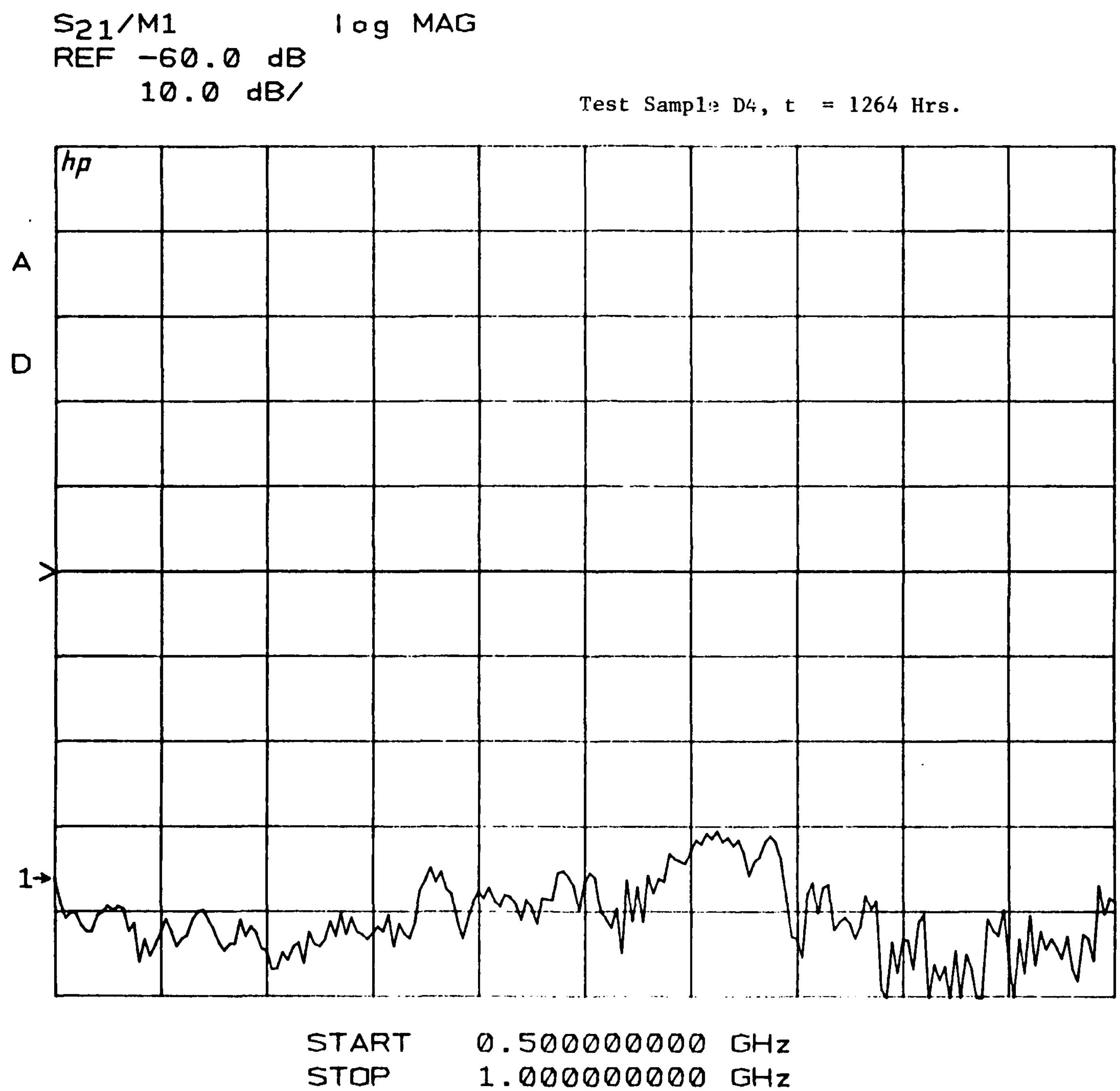

S21/M1
log MAG
REF -60.0 dB
10.0 dB/
Test Sample D1, t = 1264 Hrs.
hp
A
D
1→
START 0.500000000 GHz
STOP 1.000000000 GHz

Test Sample D2, t = 1264 Hrs.



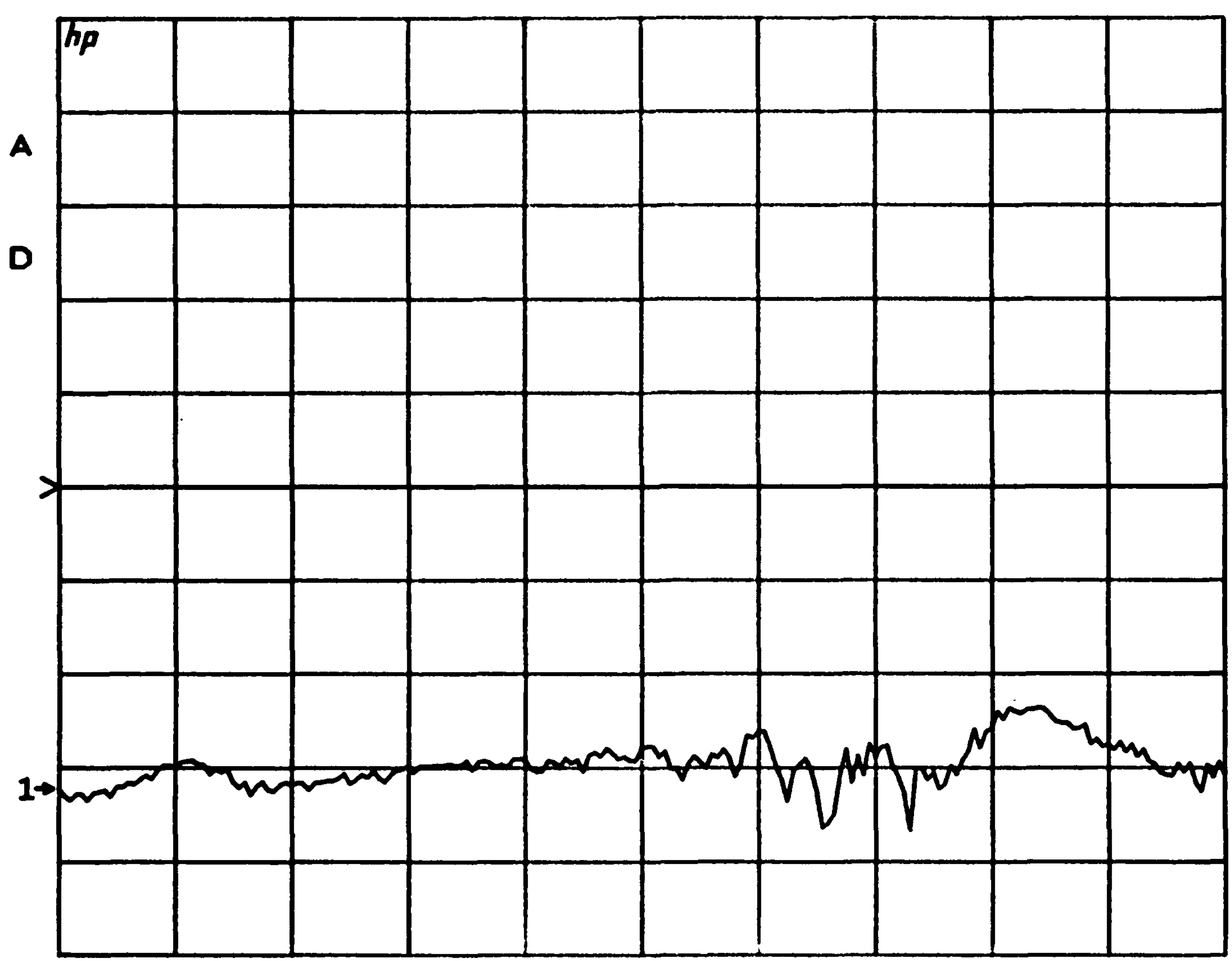
Test Sample D3, 1264 Hrs.




S21/M1
log MAG
REF -60.0 dB
10.0 dB/
Test Sample D4, t = 1264 Hrs.
hp
A
D
1→
START 0.500000000 GHz
STOP 1.000000000 GHz

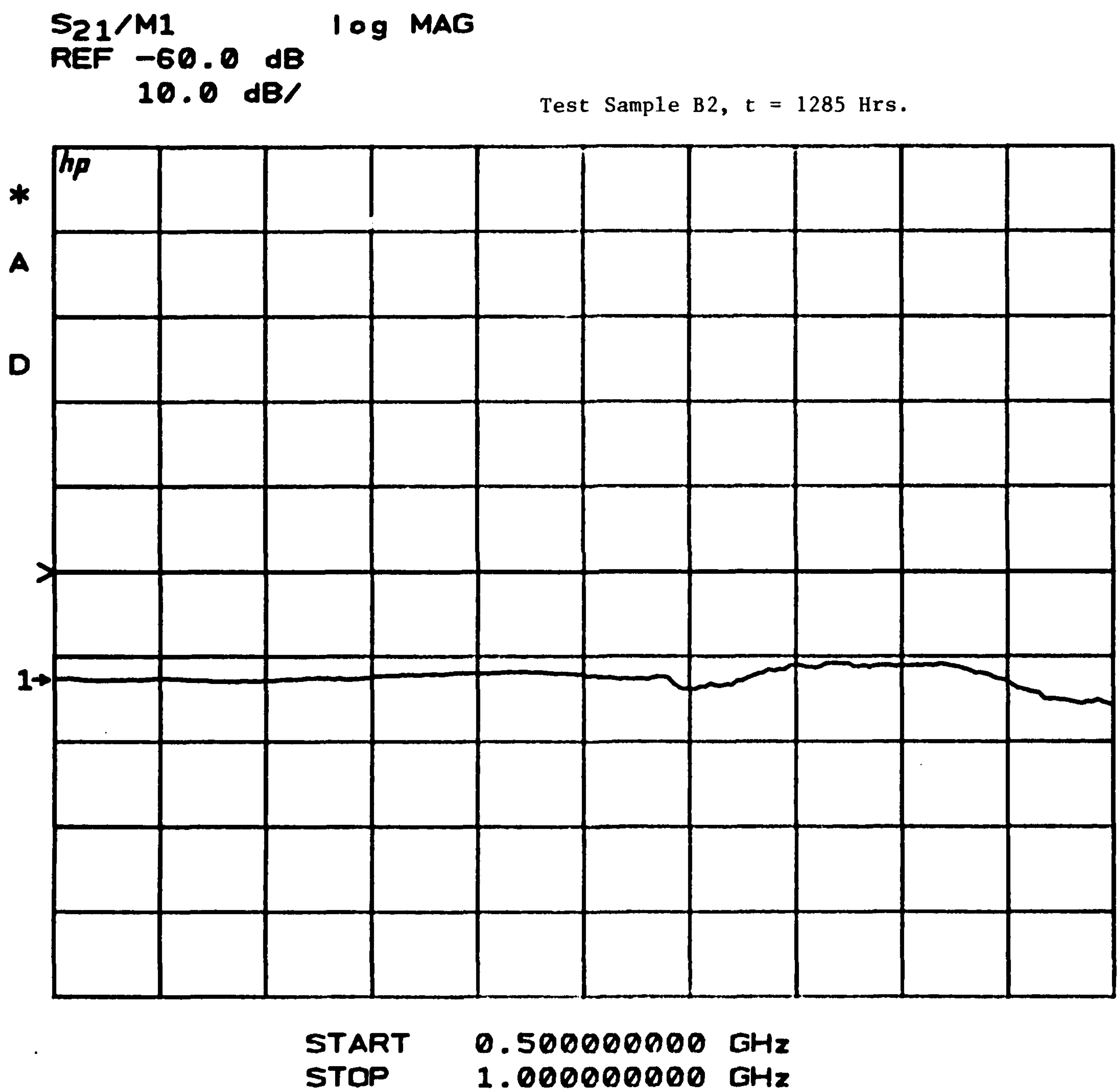
S_{21}/M1 log MAG
REF -60.0 dB
10.0 dB/

Test Sample B1, t = 1285 Hrs.



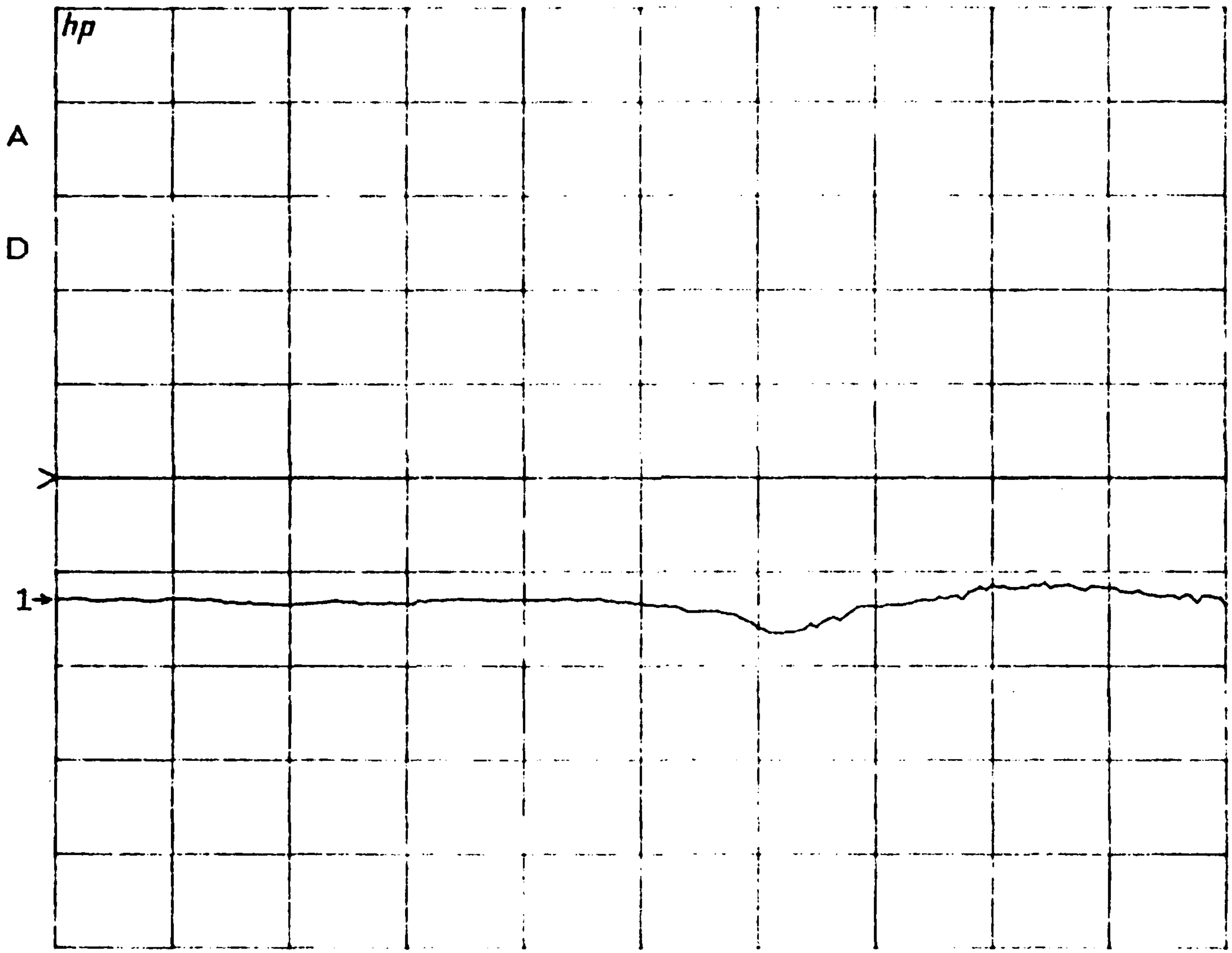
START 0.500000000 GHz
STOP 1.000000000 GHz

Test Sample B2, t = 1285 Hrs.



S21/M1 log MAG
REF -60.0 dB
10.0 dB/

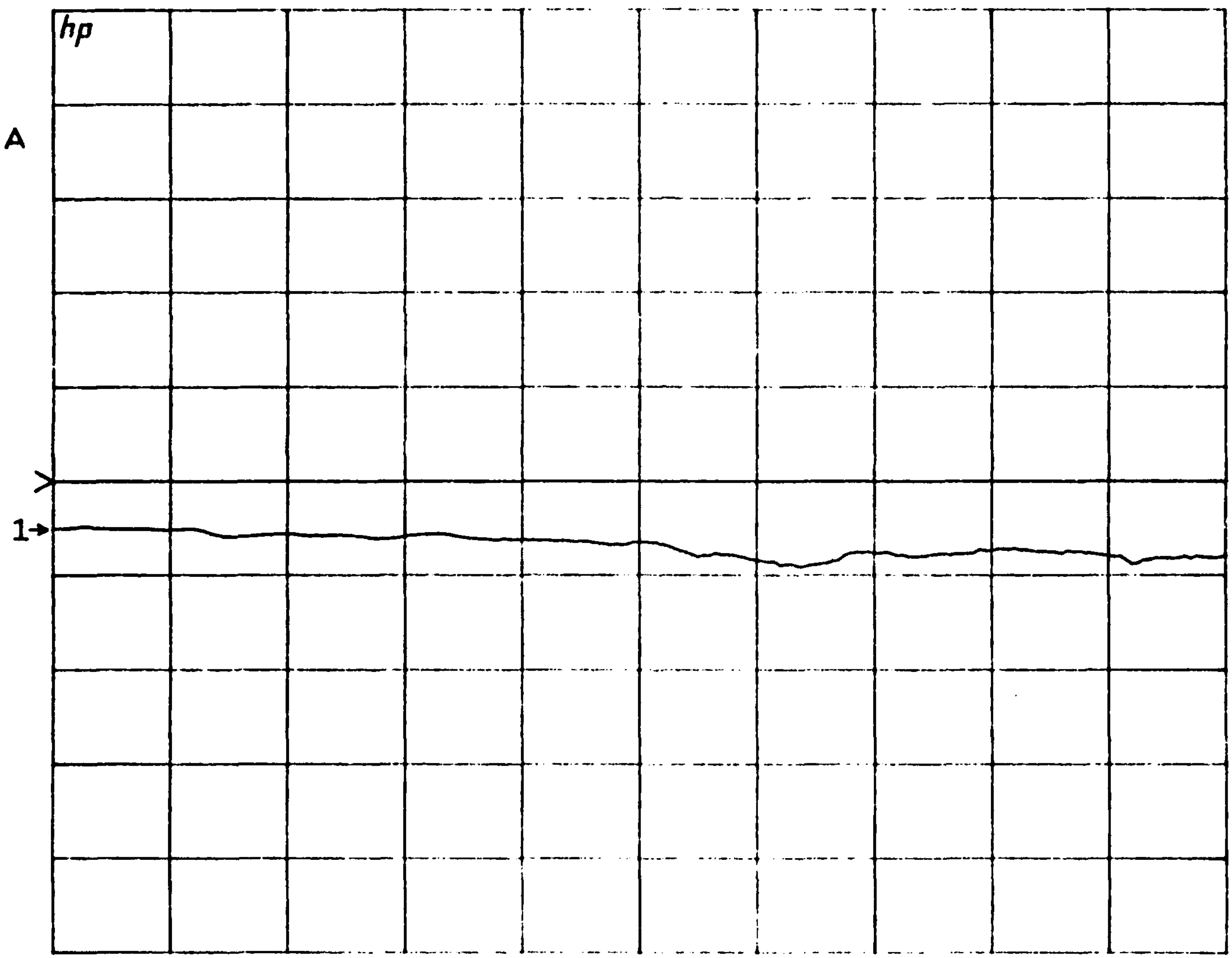
Test Sample Al, t = 1572 Hrs.



START 0.500000000 GHz
STOP 1.000000000 GHz

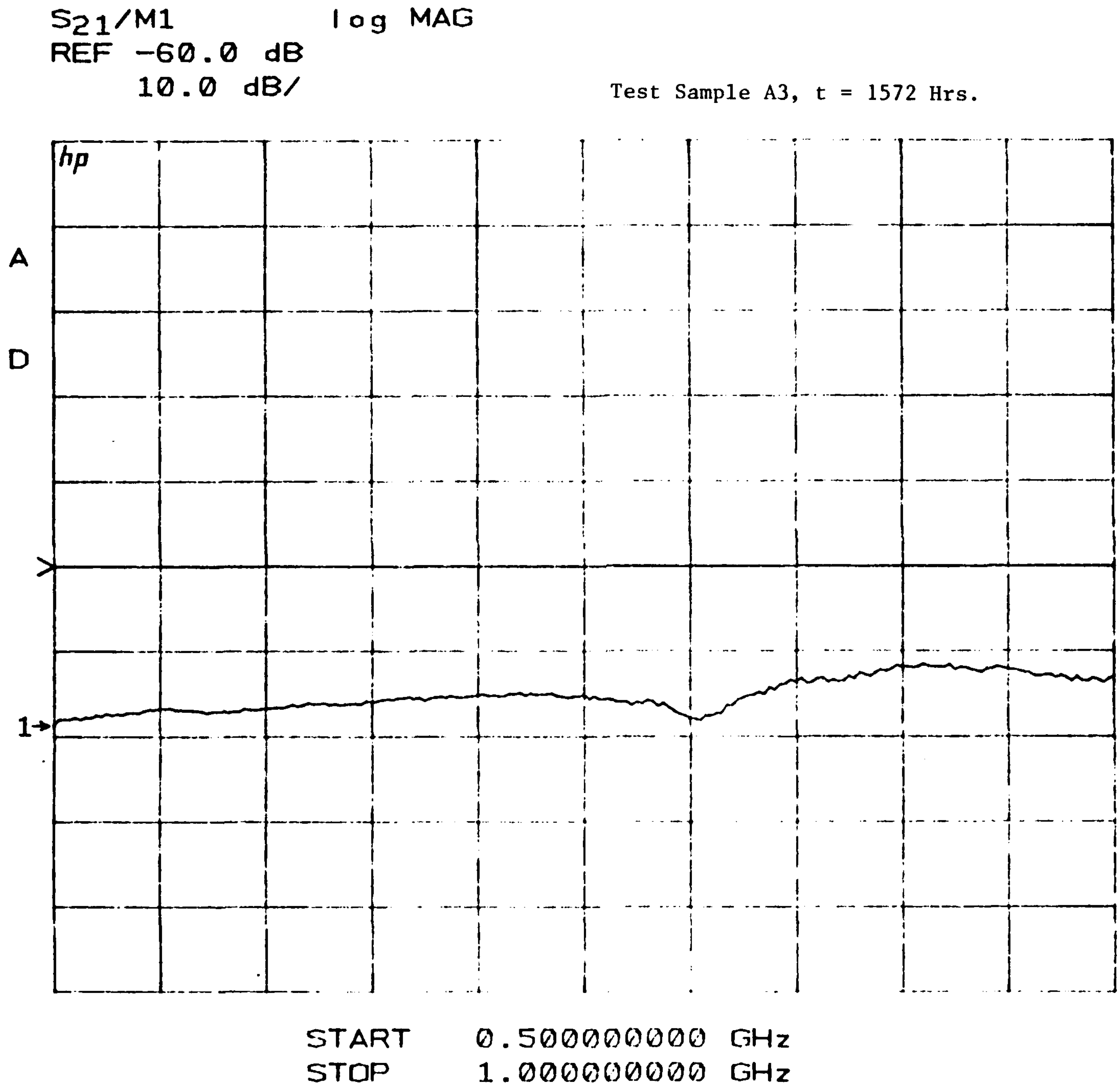
S_{21}/M1 log MAG
REF −60.0 dB
10.0 dB/

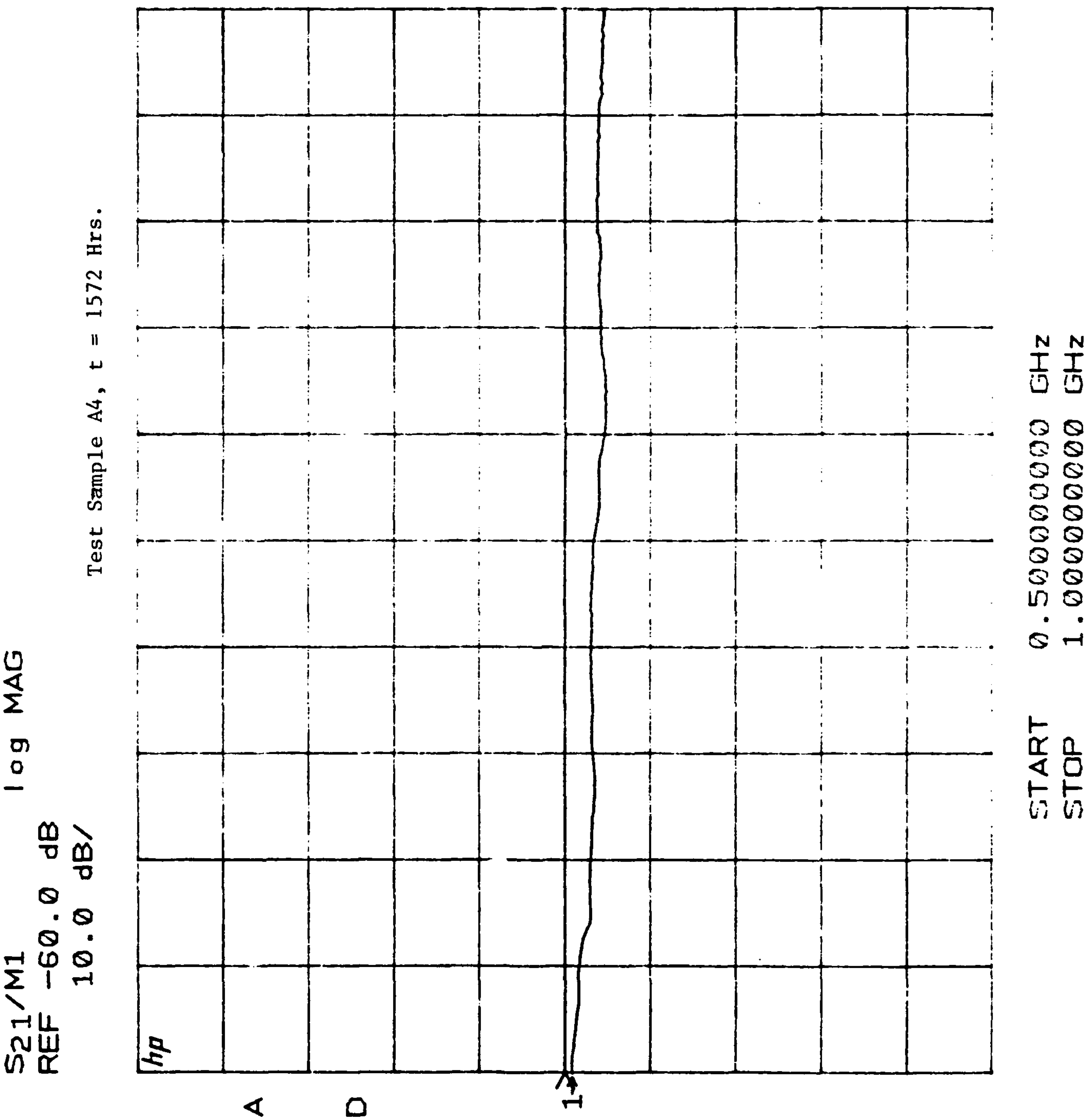
Test Sample A2, t = 1572 Hrs.



START 0.500000000 GHz
STOP 1.000000000 GHz

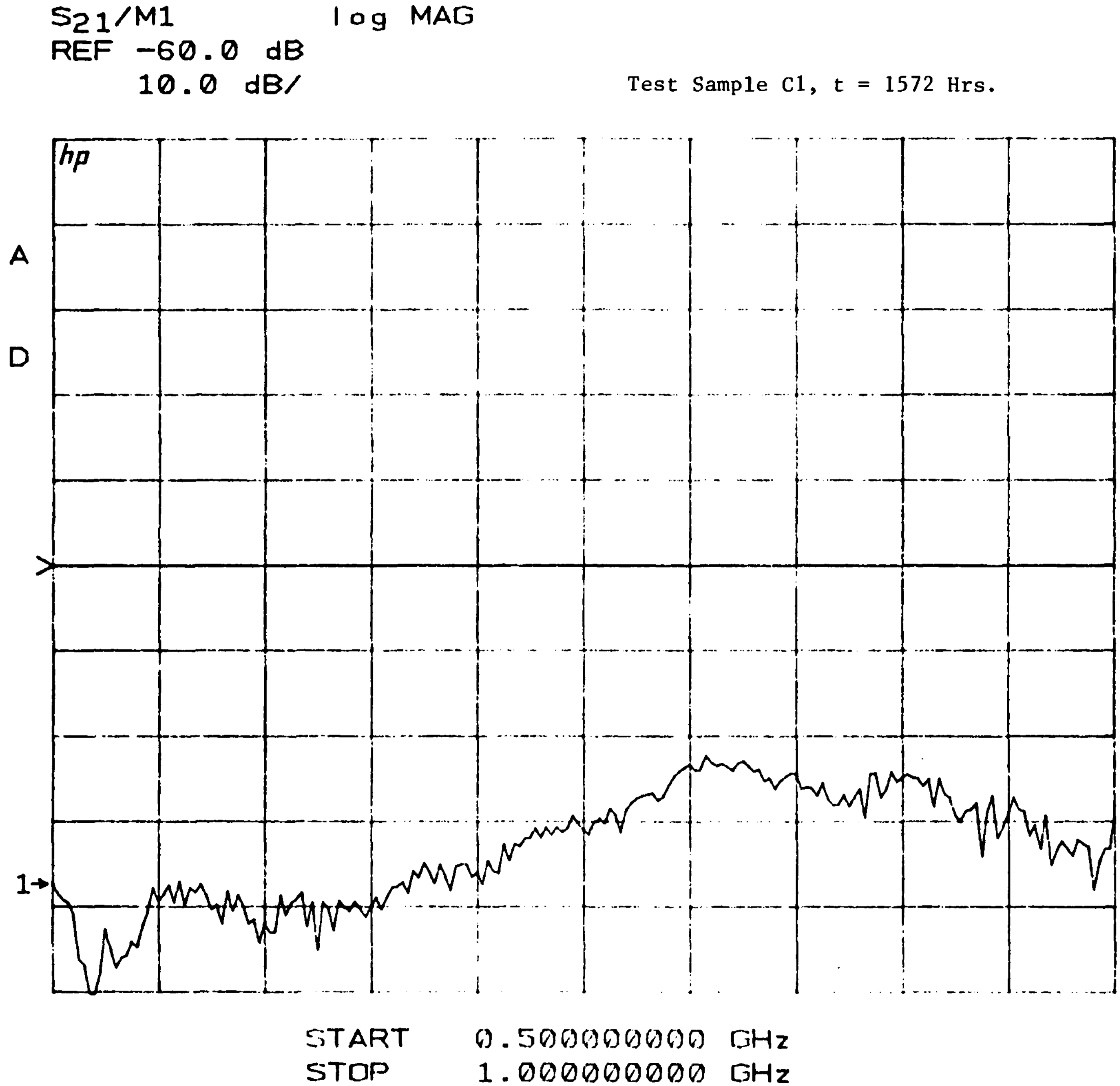
Test Sample A3, t = 1572 Hrs.



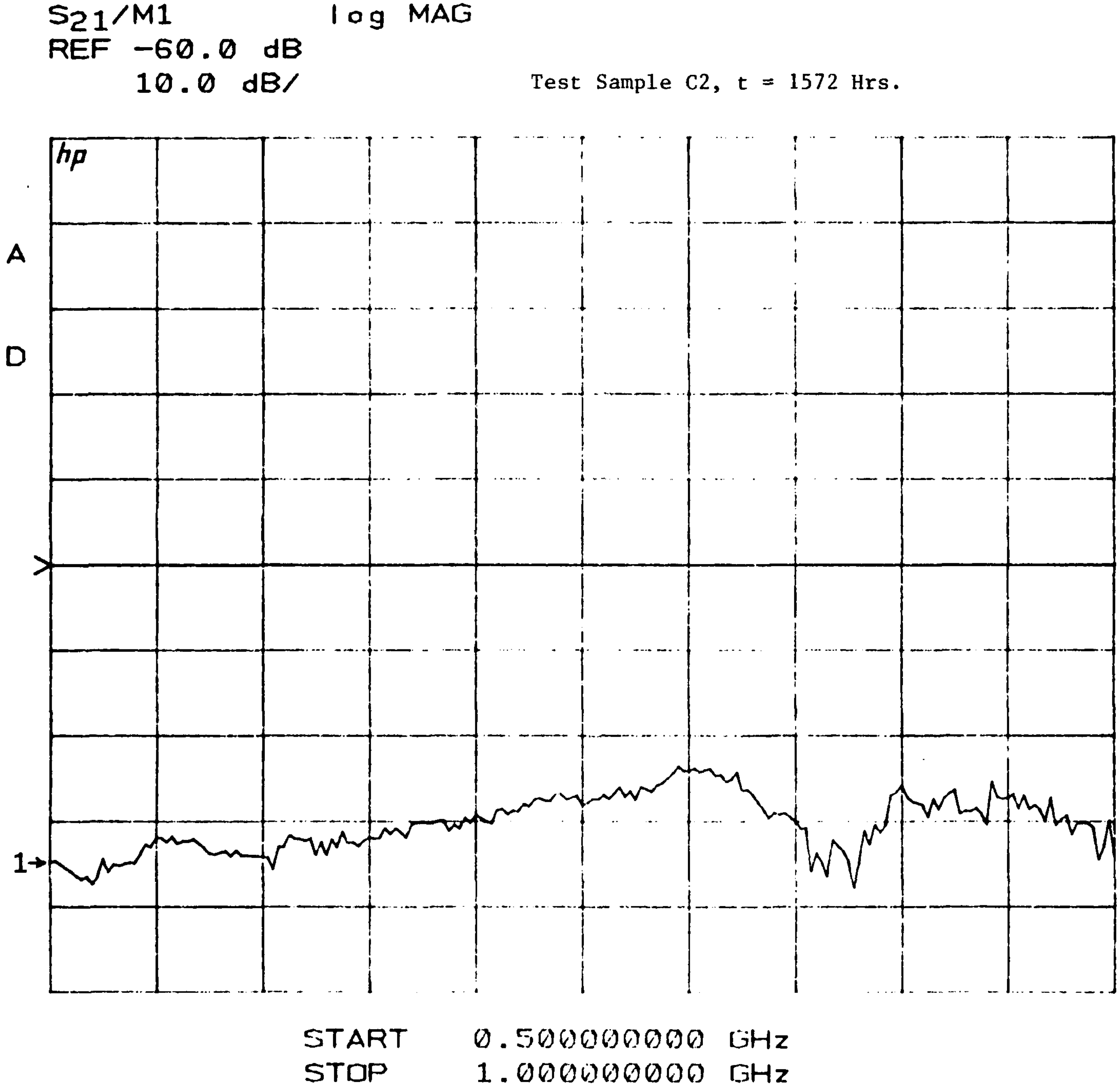


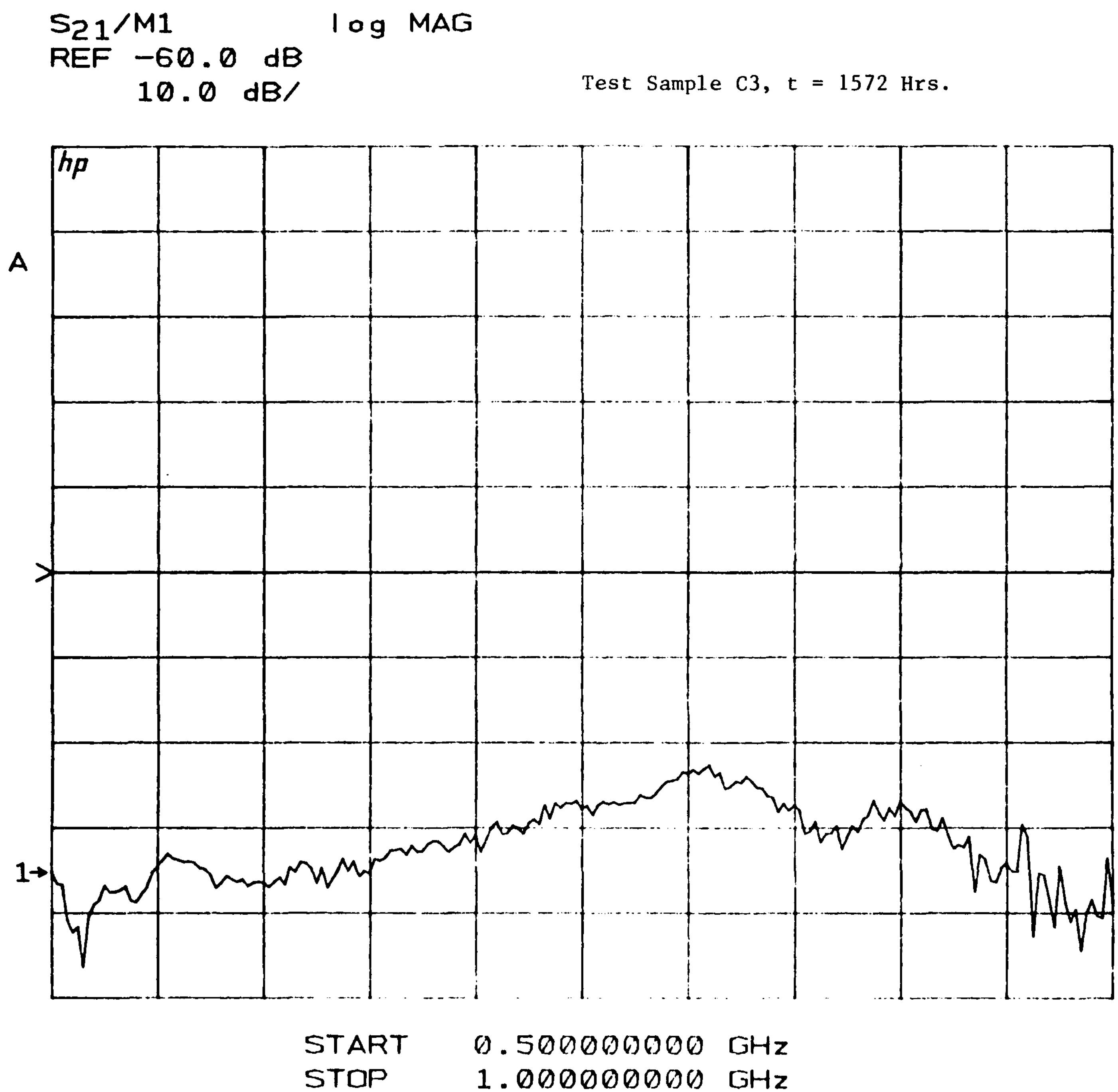
Test Sample A4, t = 1572 Hrs.

Test Sample C1, t = 1572 Hrs.

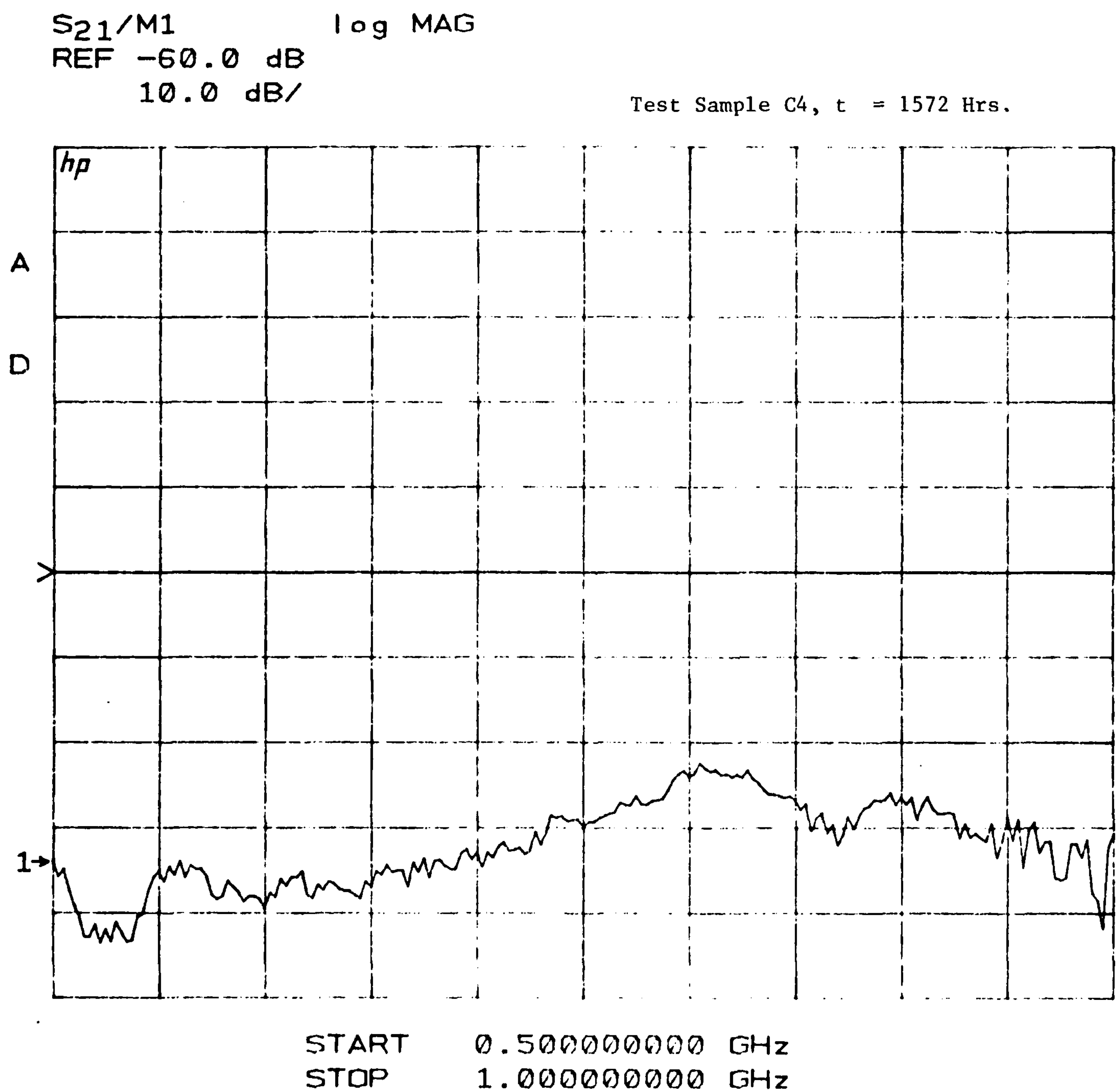


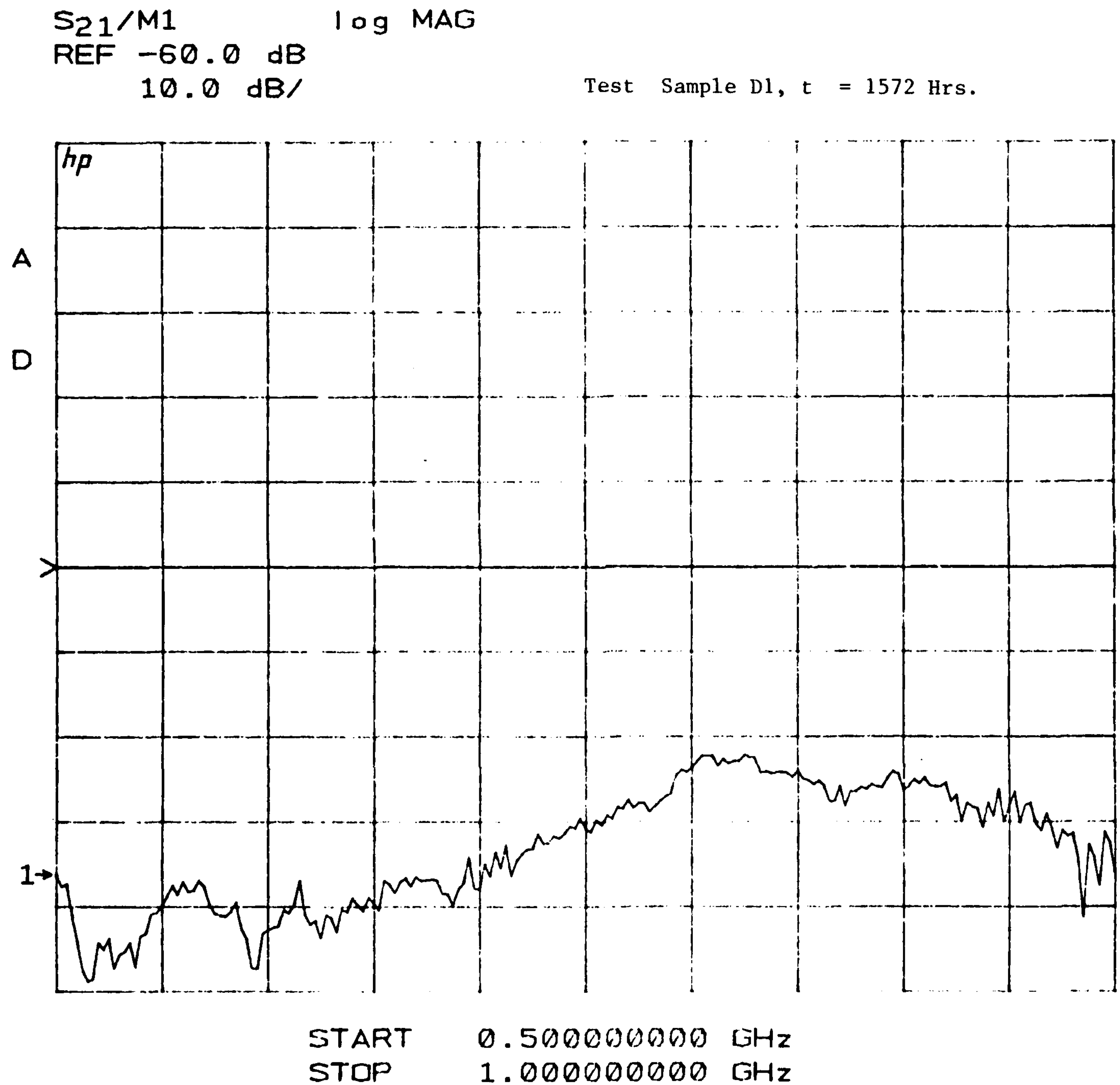
Test Sample C2, t = 1572 Hrs.



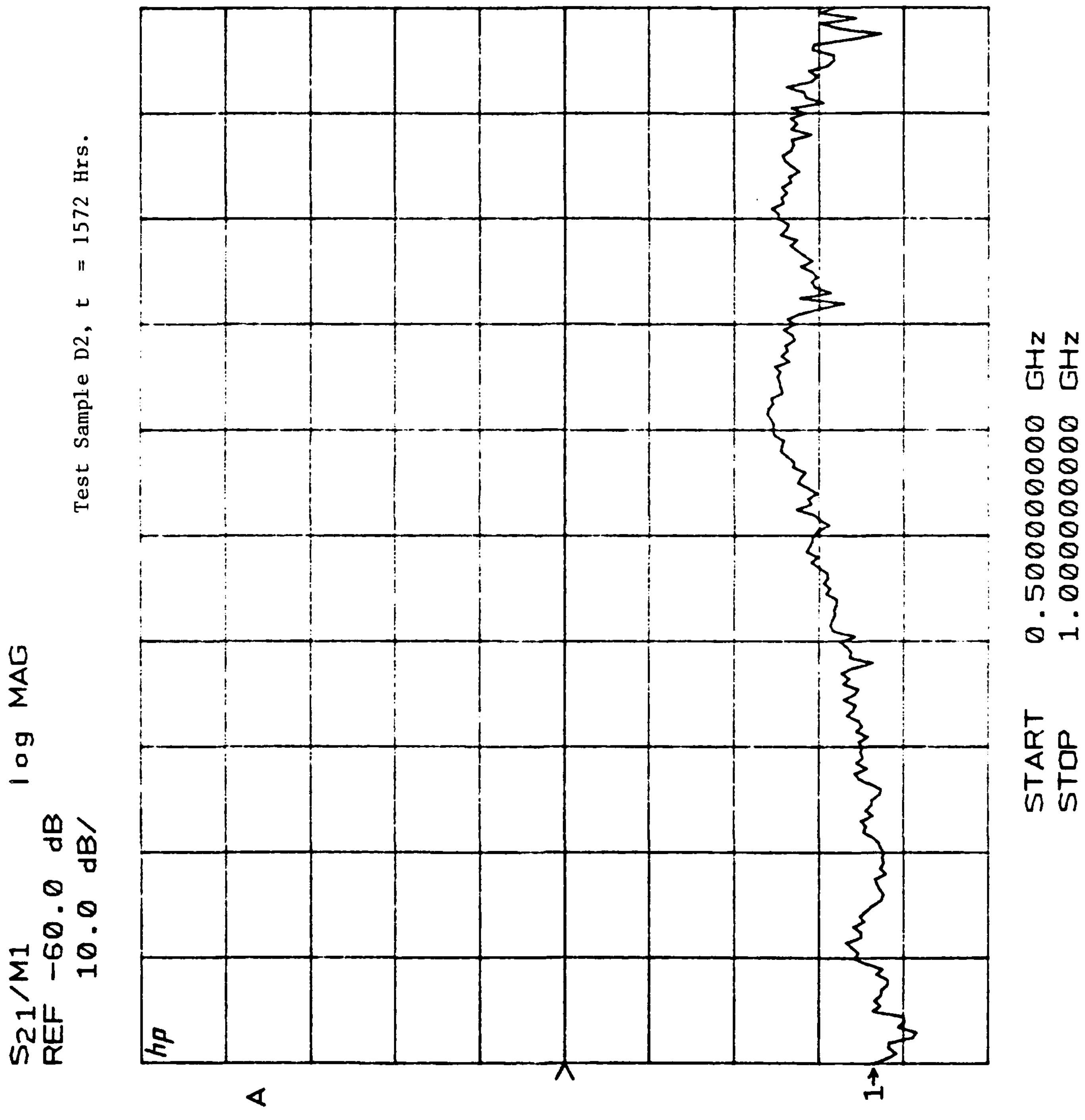


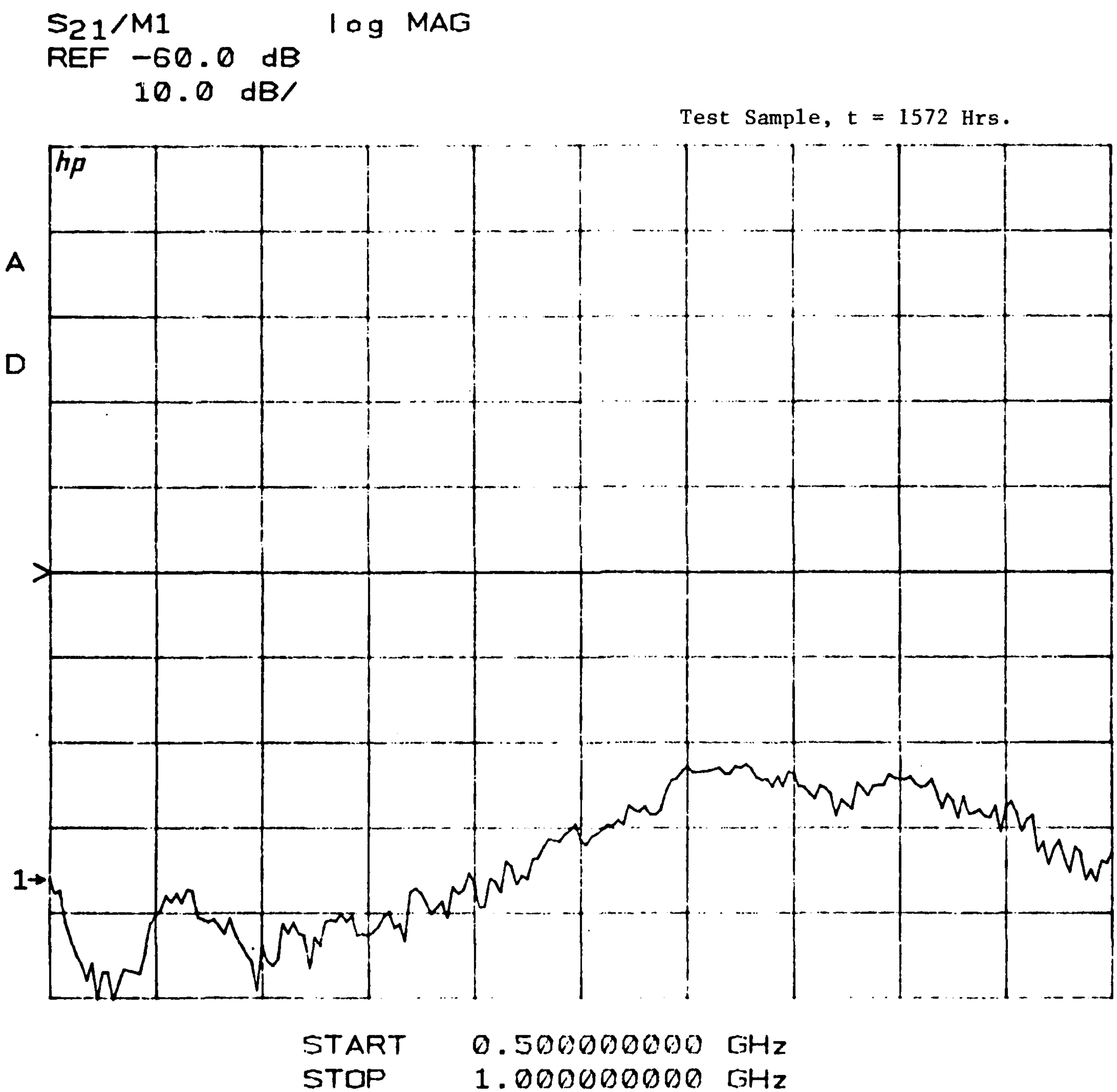
S_{21}/M1 log MAG
REF -60.0 dB
10.0 dB/
Test Sample C3, t = 1572 Hrs.
hp
A
1→
START 0.500000000 GHz
STOP 1.000000000 GHz


S21/M1 log MAG
REF -60.0 dB
10.0 dB/
Test Sample C4, t = 1572 Hrs.
hp
A
D
1→
START 0.500000000 GHz
STOP 1.000000000 GHz



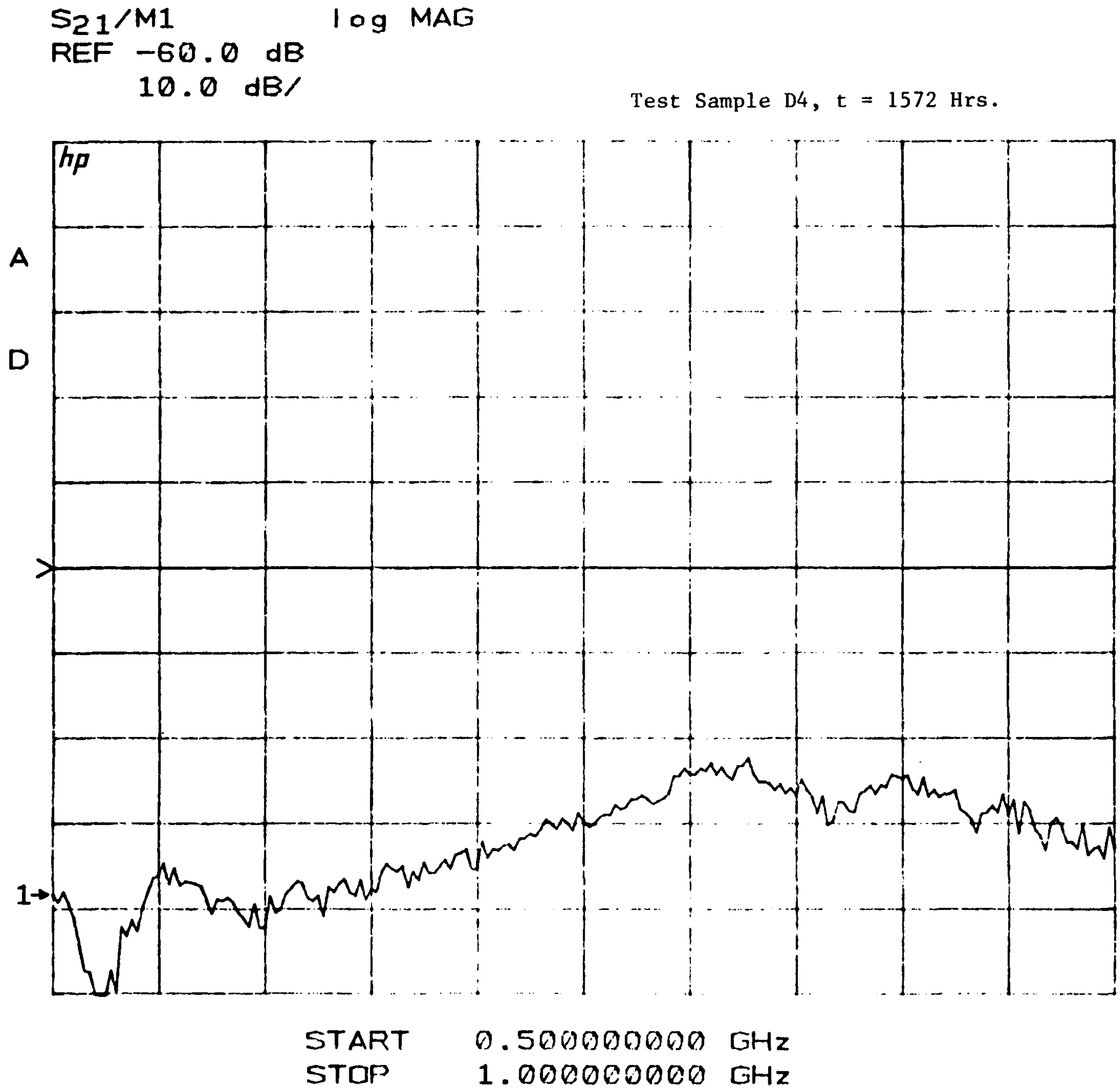
S21/M1 log MAG
REF -60.0 dB
10.0 dB/
Test Sample D1, t = 1572 Hrs.
hp
A
D
1
START 0.500000000 GHz
STOP 1.000000000 GHz


S21/M1 log MAG
REF -60.0 dB
10.0 dB/
hp
A
1
Test Sample D2, t = 1572 Hrs.
START 0.500000000 GHz
STOP 1.000000000 GHz

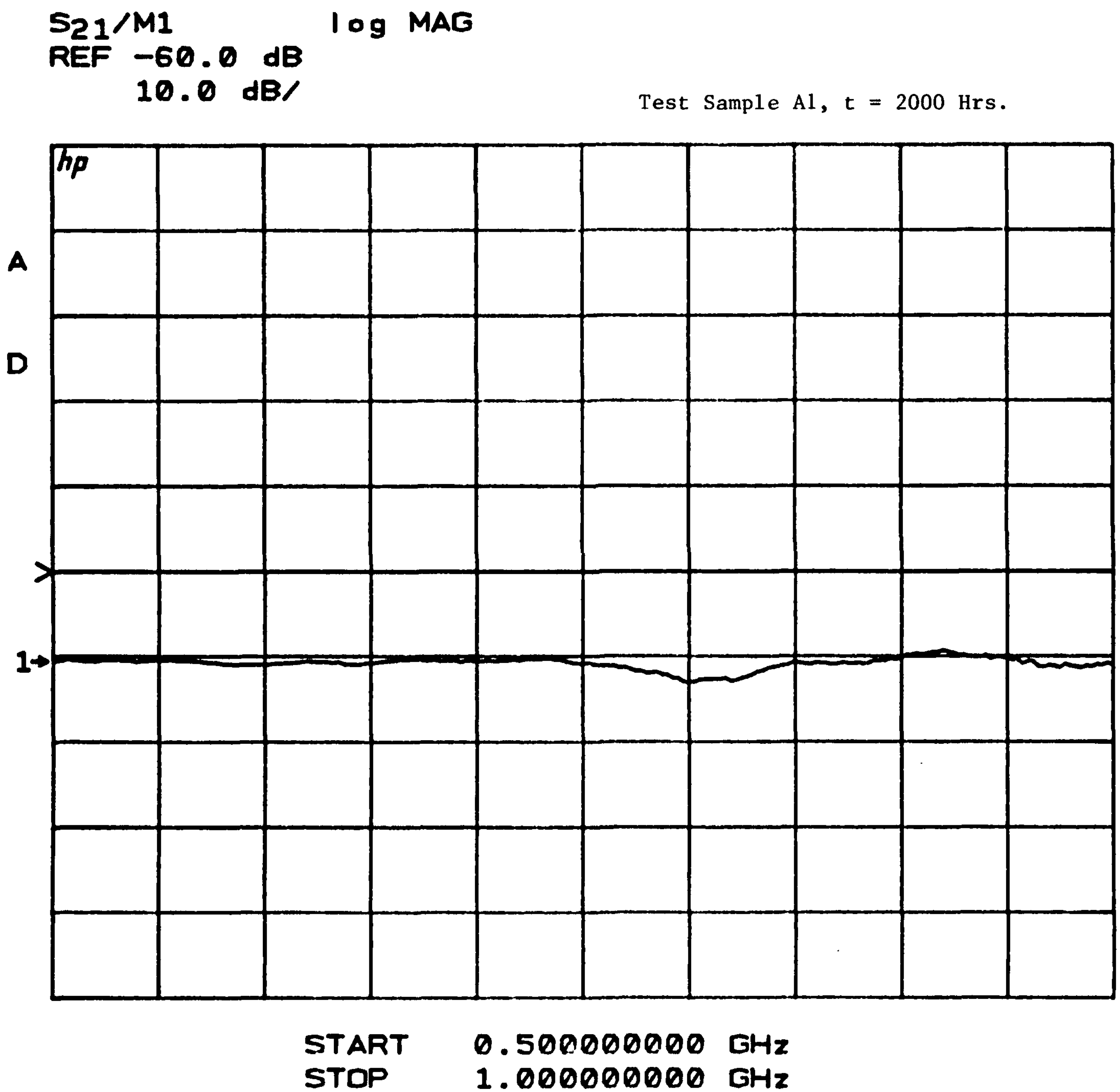


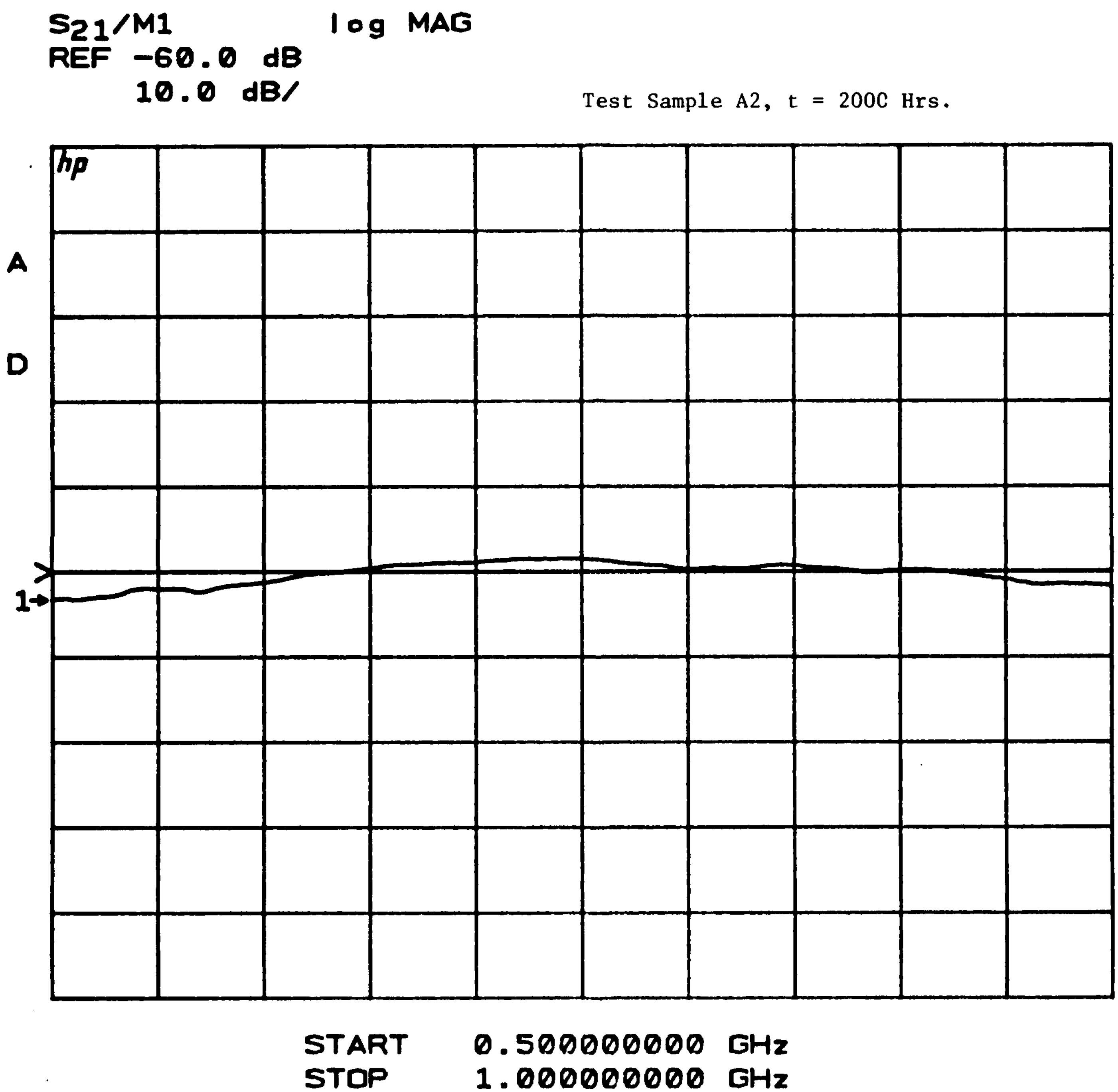
S21/M1 log MAG
REF -60.0 dB
10.0 dB/
Test Sample, t = 1572 Hrs.
hp
A
D
1
START 0.500000000 GHz
STOP 1.000000000 GHz

Test Sample D4, t = 1572 Hrs.

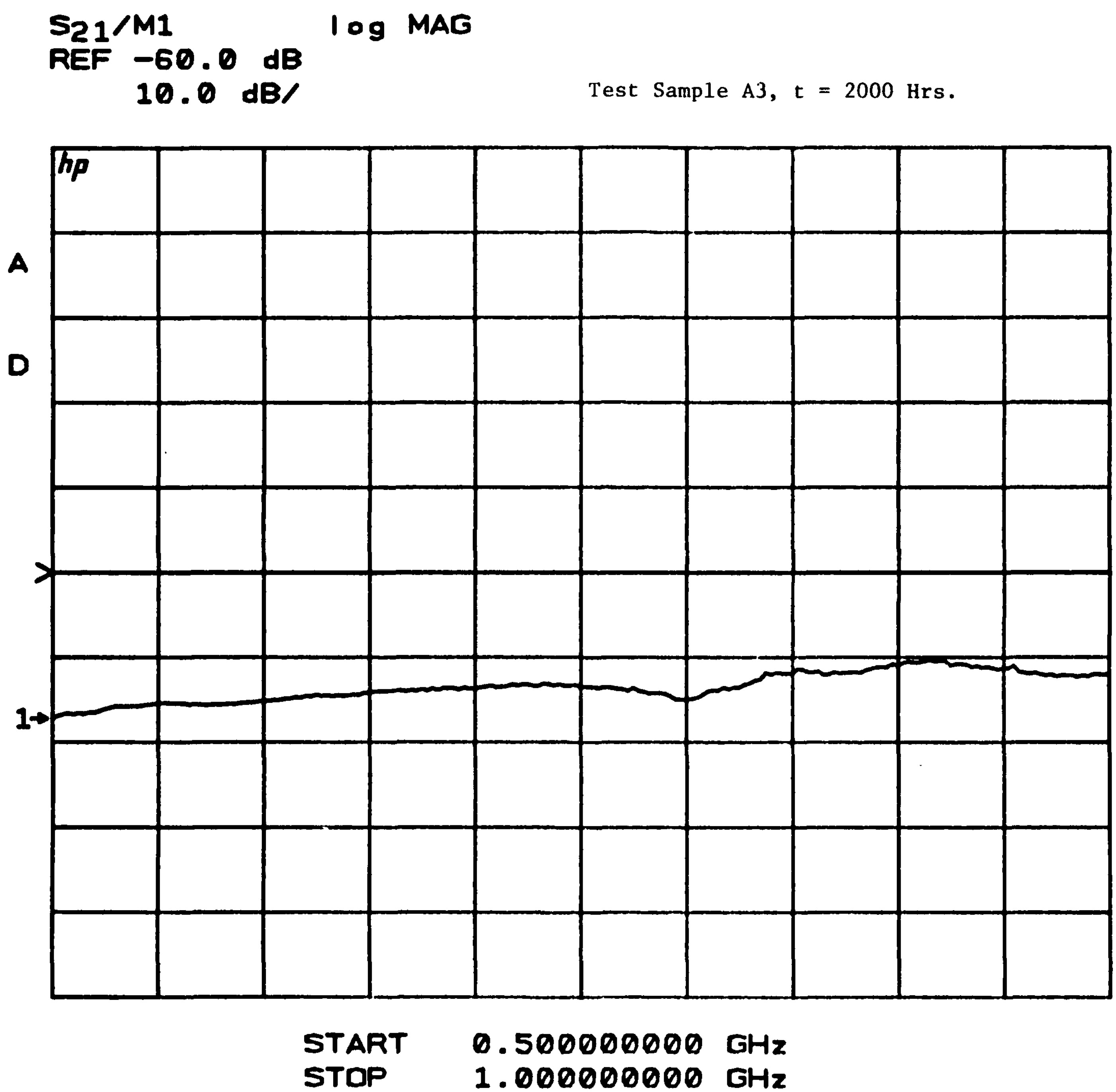


Test Sample Al, t = 2000 Hrs.



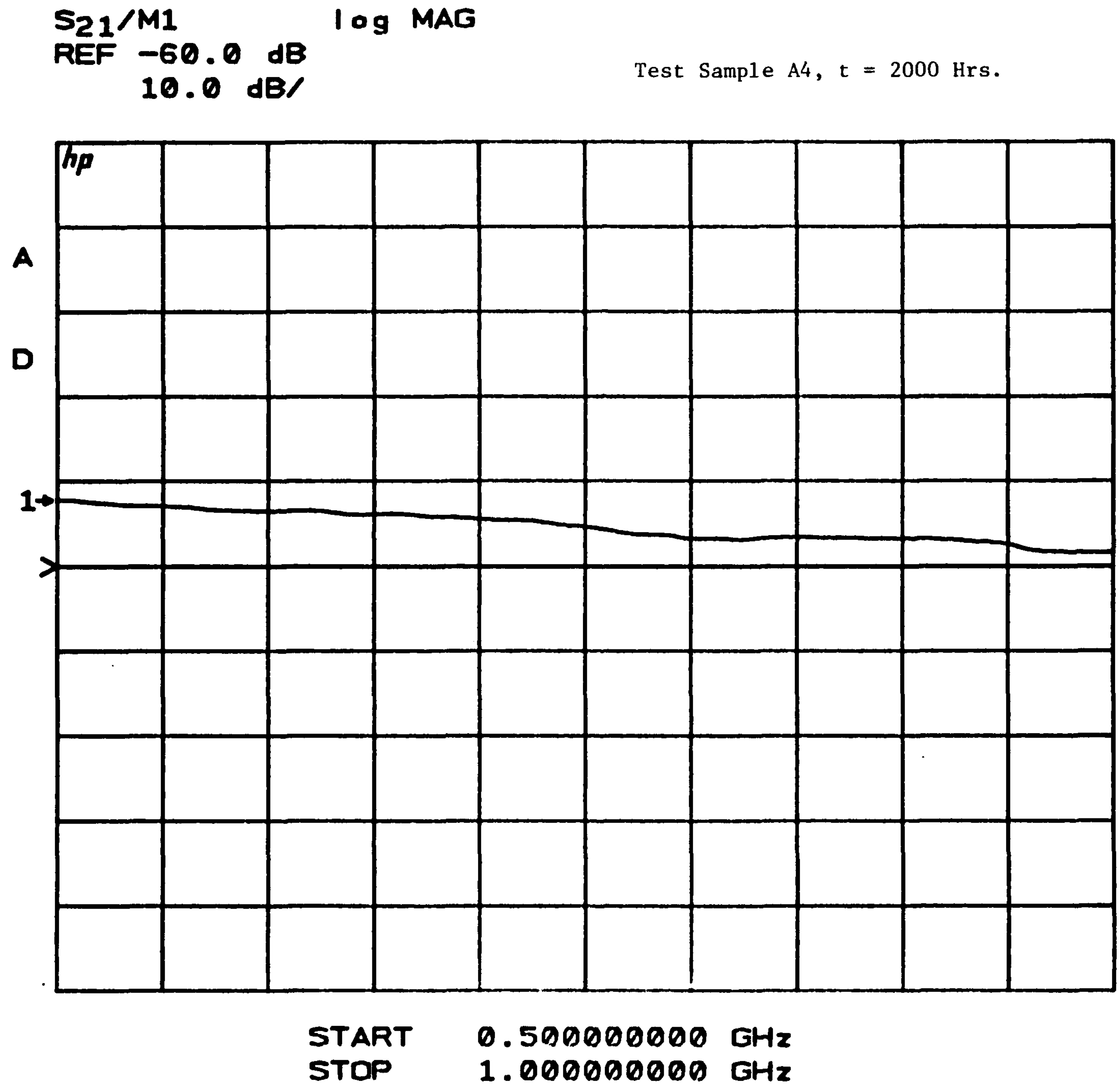


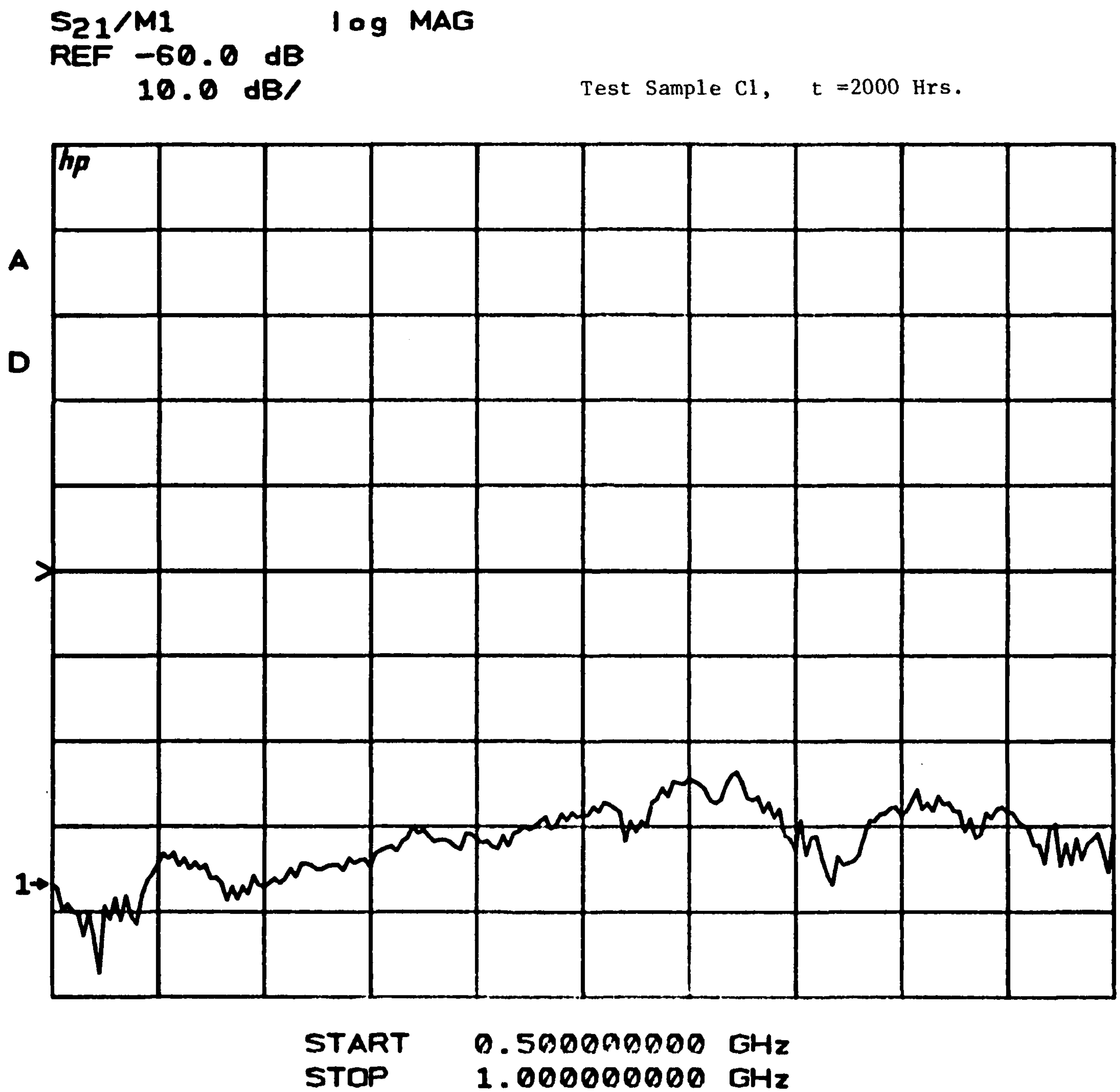
S21/M1 log MAG
REF -60.0 dB
10.0 dB/
Test Sample A2, t = 200C Hrs.
hp
A
D
1
START 0.500000000 GHz
STOP 1.000000000 GHz



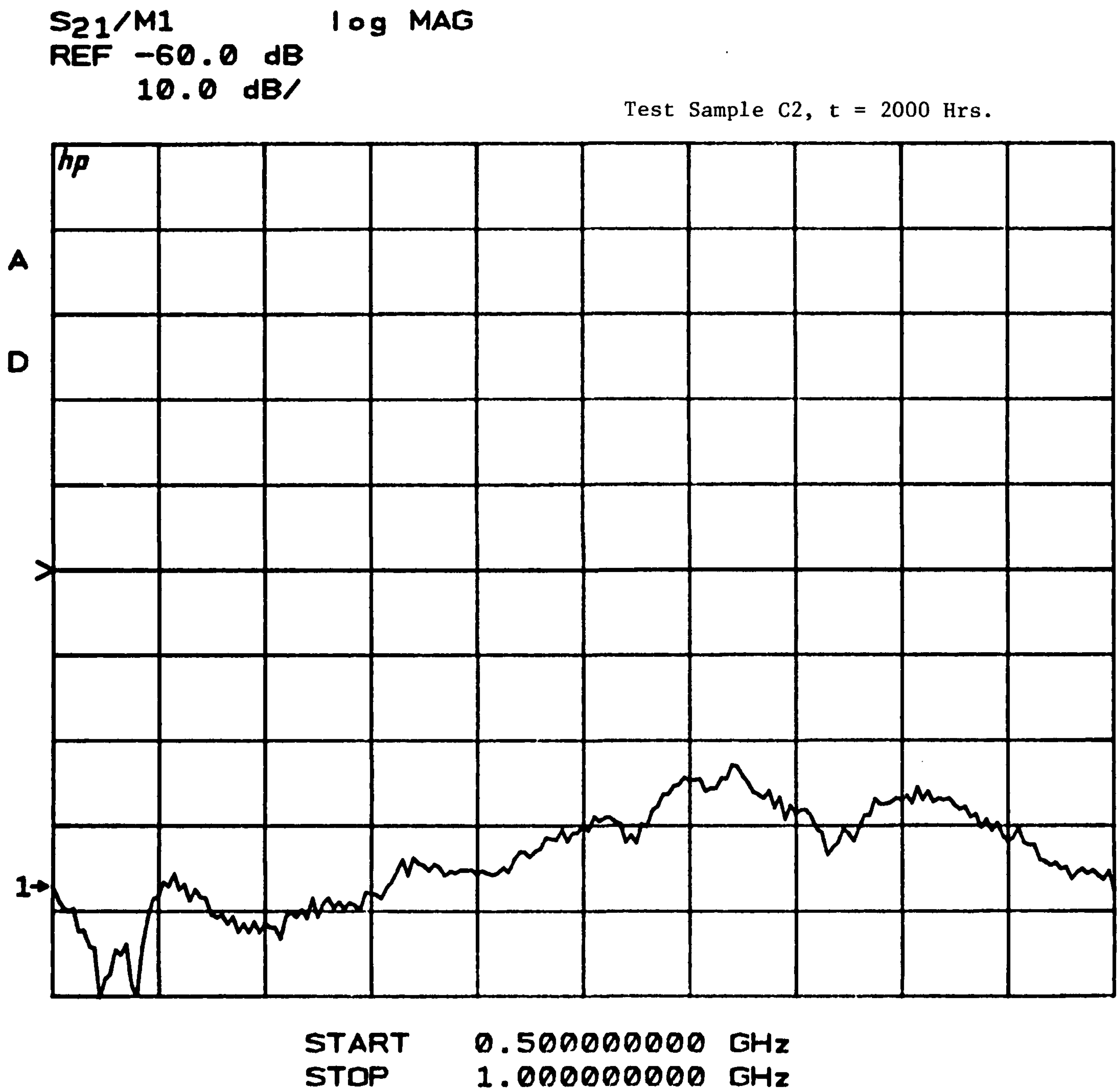
S_{21}/M1 log MAG
REF -60.0 dB
10.0 dB/
Test Sample A3, t = 2000 Hrs.
hp
A
D
1
START 0.500000000 GHz
STOP 1.000000000 GHz

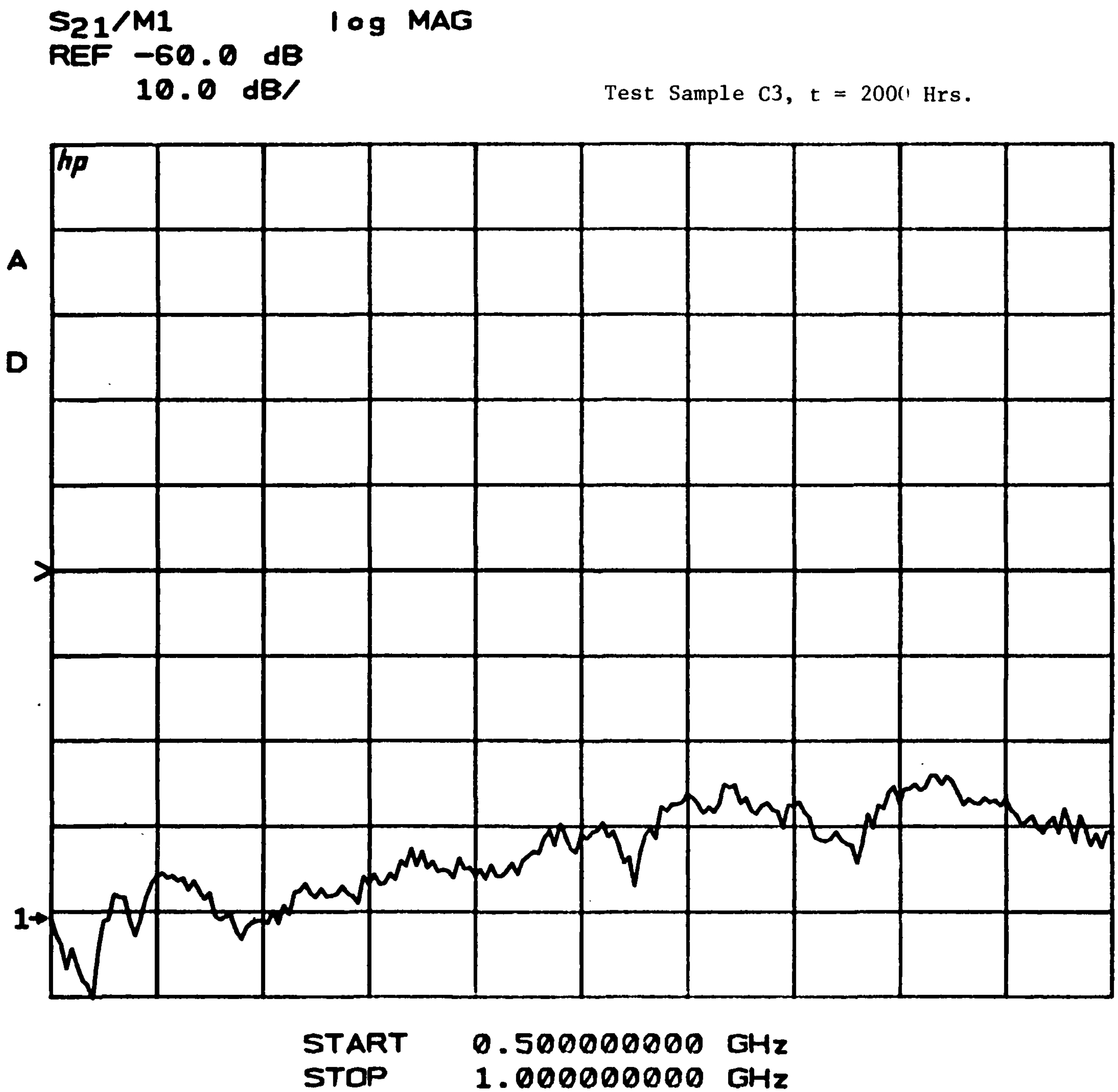
Test Sample A4, t = 2000 Hrs.



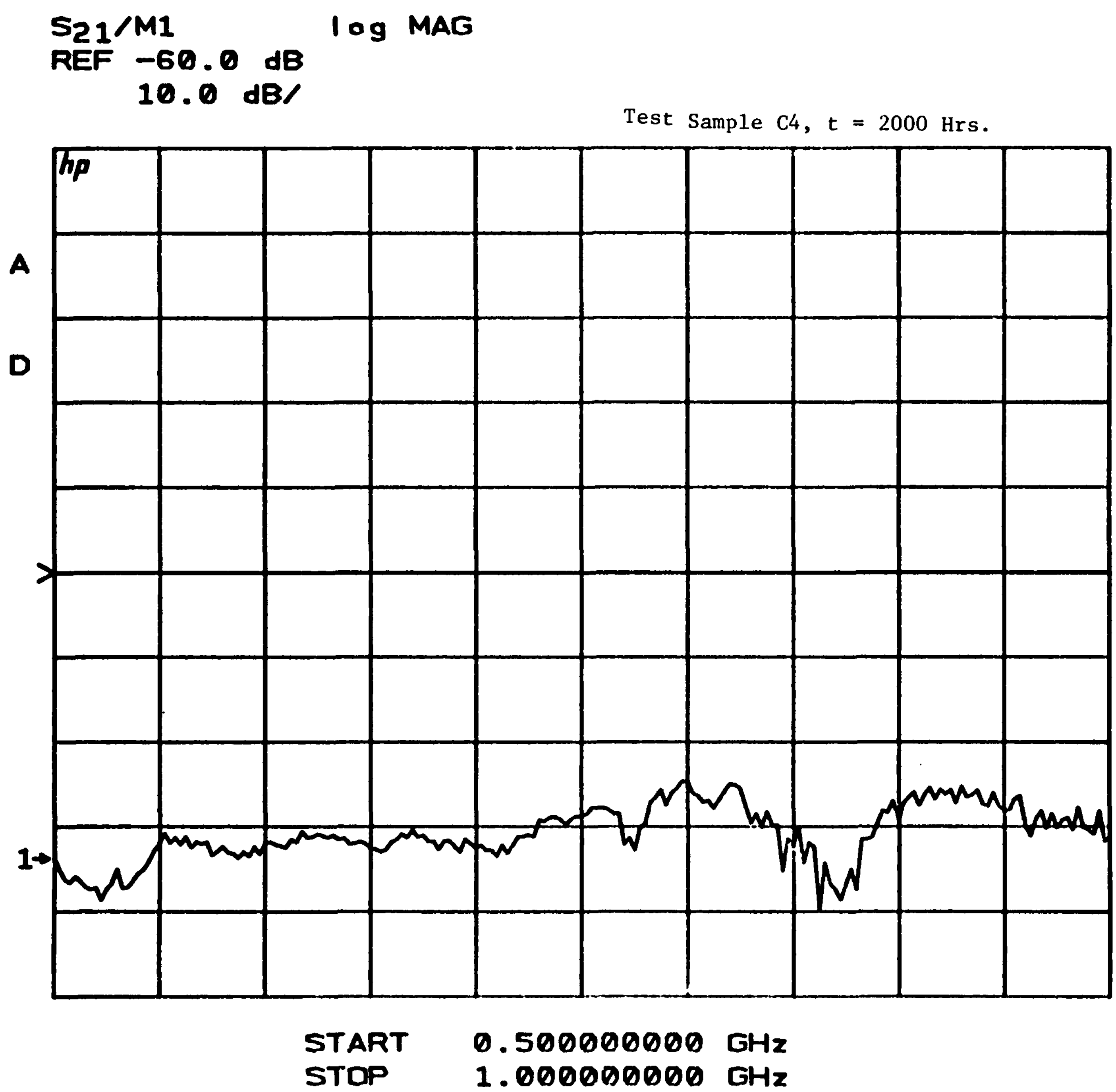

S21/M1 log MAG
REF -60.0 dB
10.0 dB/
Test Sample C1, t =2000 Hrs.
hp
A
D
1
START 0.500000000 GHz
STOP 1.000000000 GHz

Test Sample C2, t = 2000 Hrs.

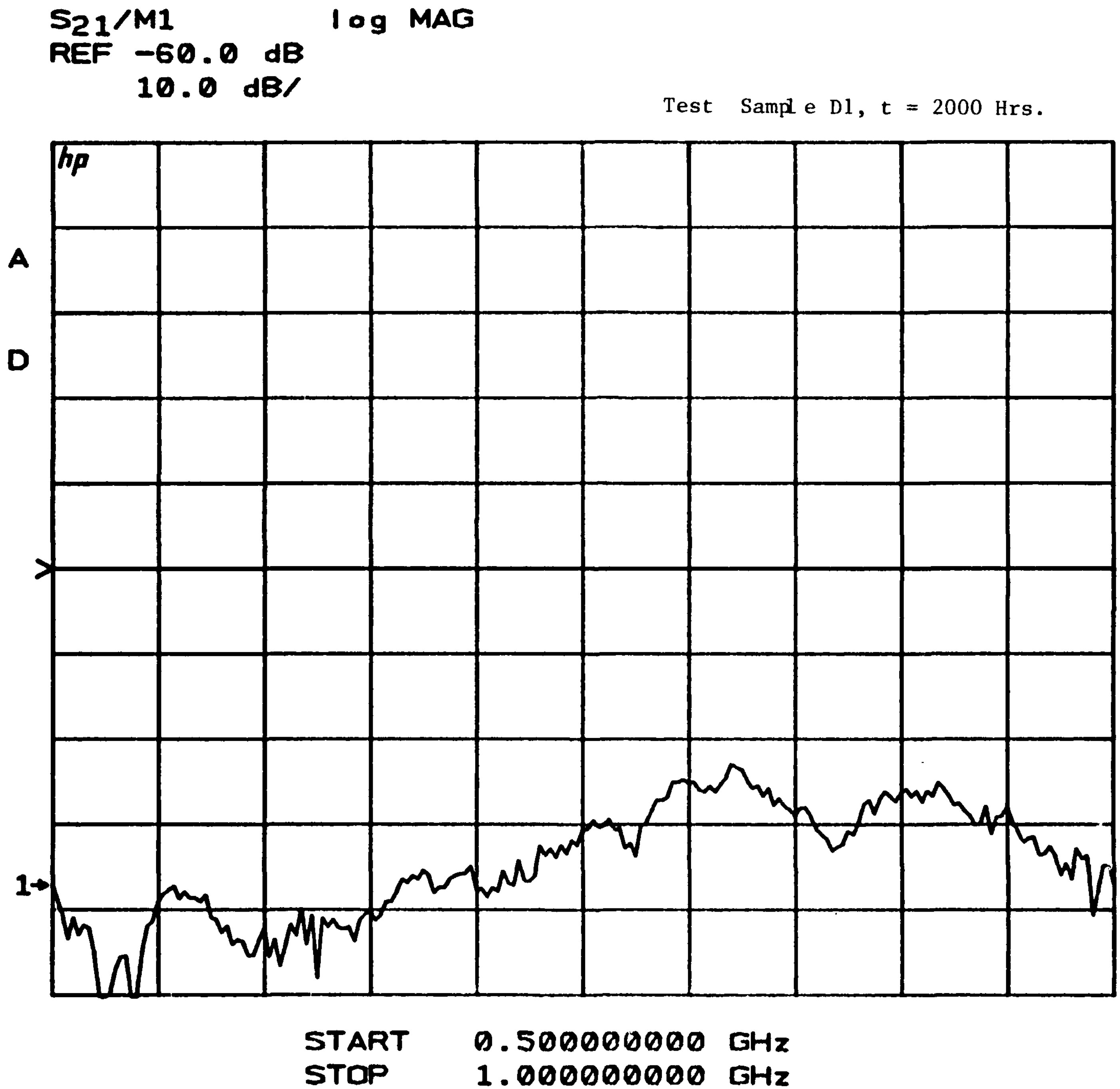


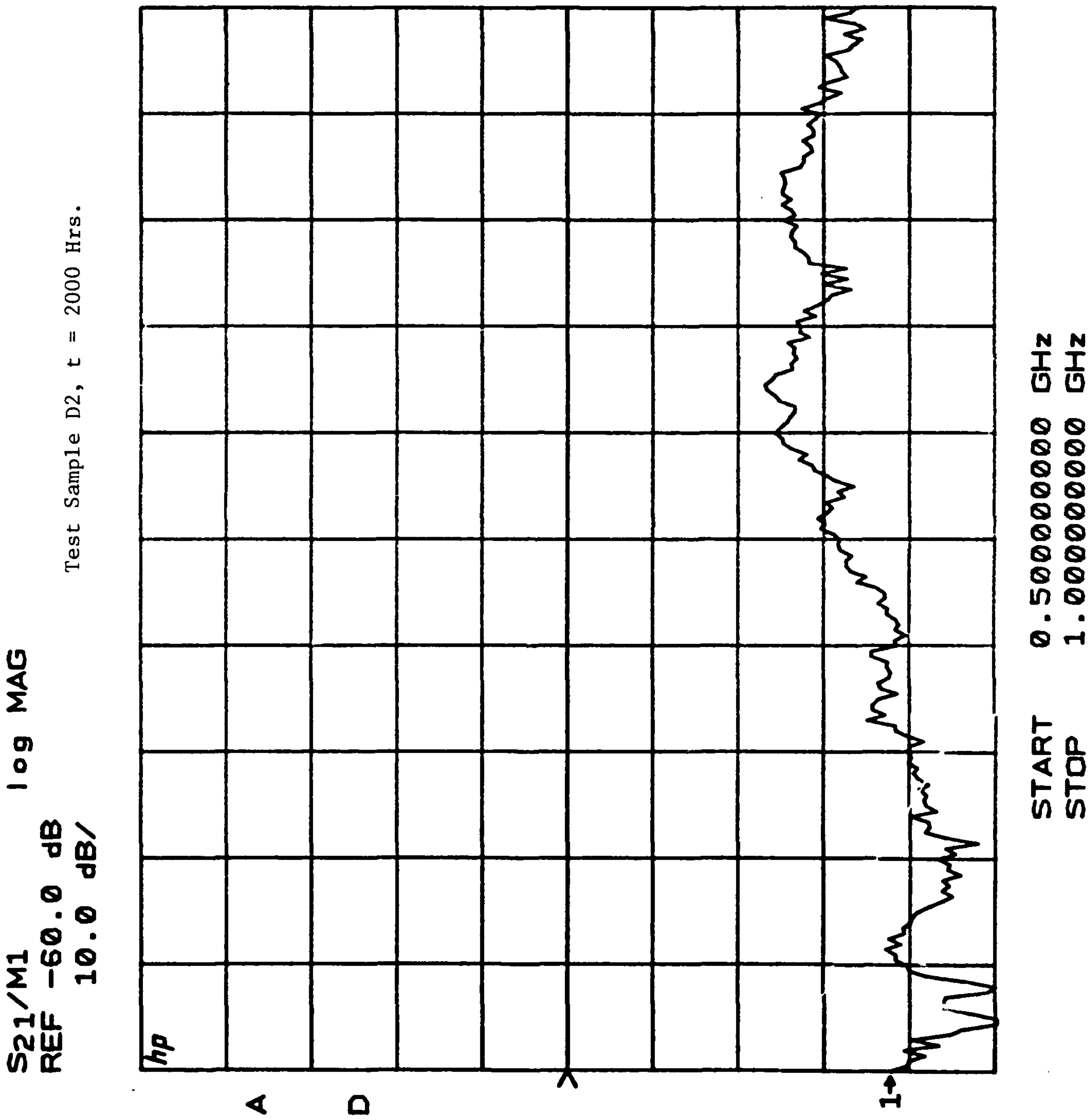


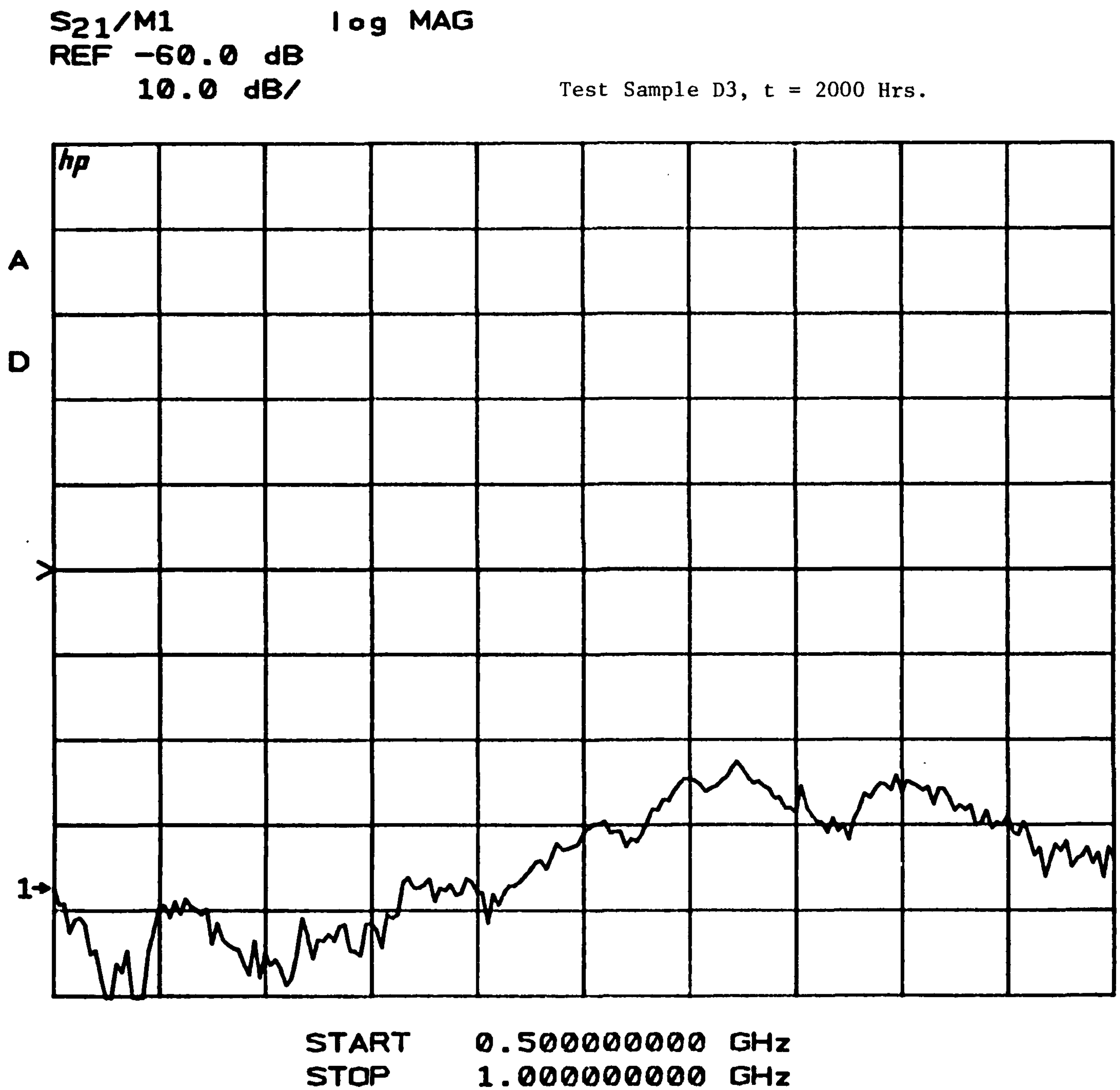
Test Sample C3, t = 2000 Hrs.



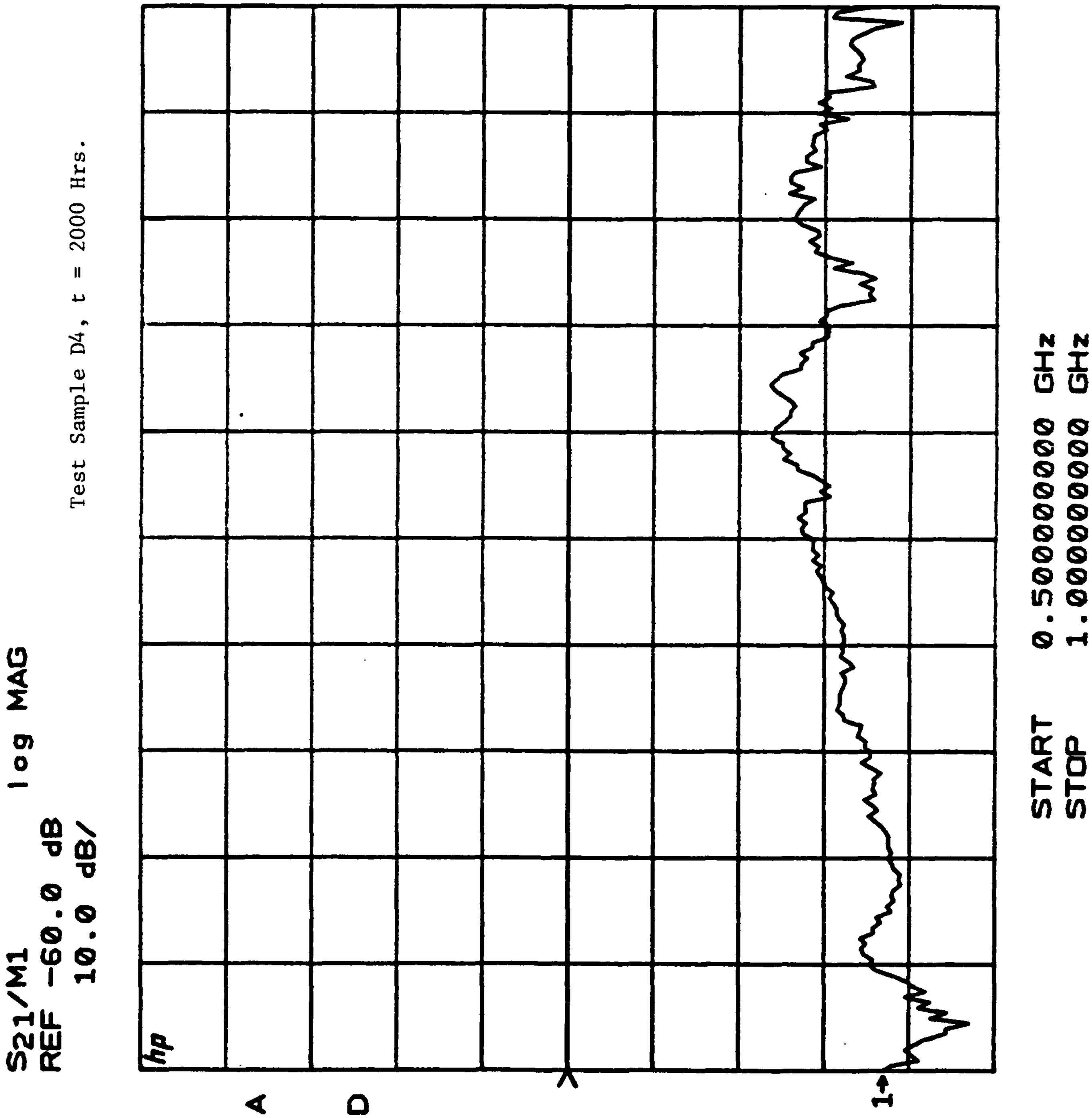
S_{21}/M1 log MAG
REF -60.0 dB
10.0 dB/
Test Sample C4, t = 2000 Hrs.
hp
A
D
1
START 0.500000000 GHz
STOP 1.000000000 GHz


S21/M1
log MAG
REF -60.0 dB
10.0 dB/
Test Sample D1, t = 2000 Hrs.
hp
A
D
1
START 0.500000000 GHz
STOP 1.000000000 GHz


S21/M1 log MAG
REF -60.0 dB
10.0 dB/
Test Sample D2, t = 2000 Hrs.
hp
A
D
1
START 0.500000000 GHz
STOP 1.000000000 GHz



Test Sample D3, t = 2000 Hrs.

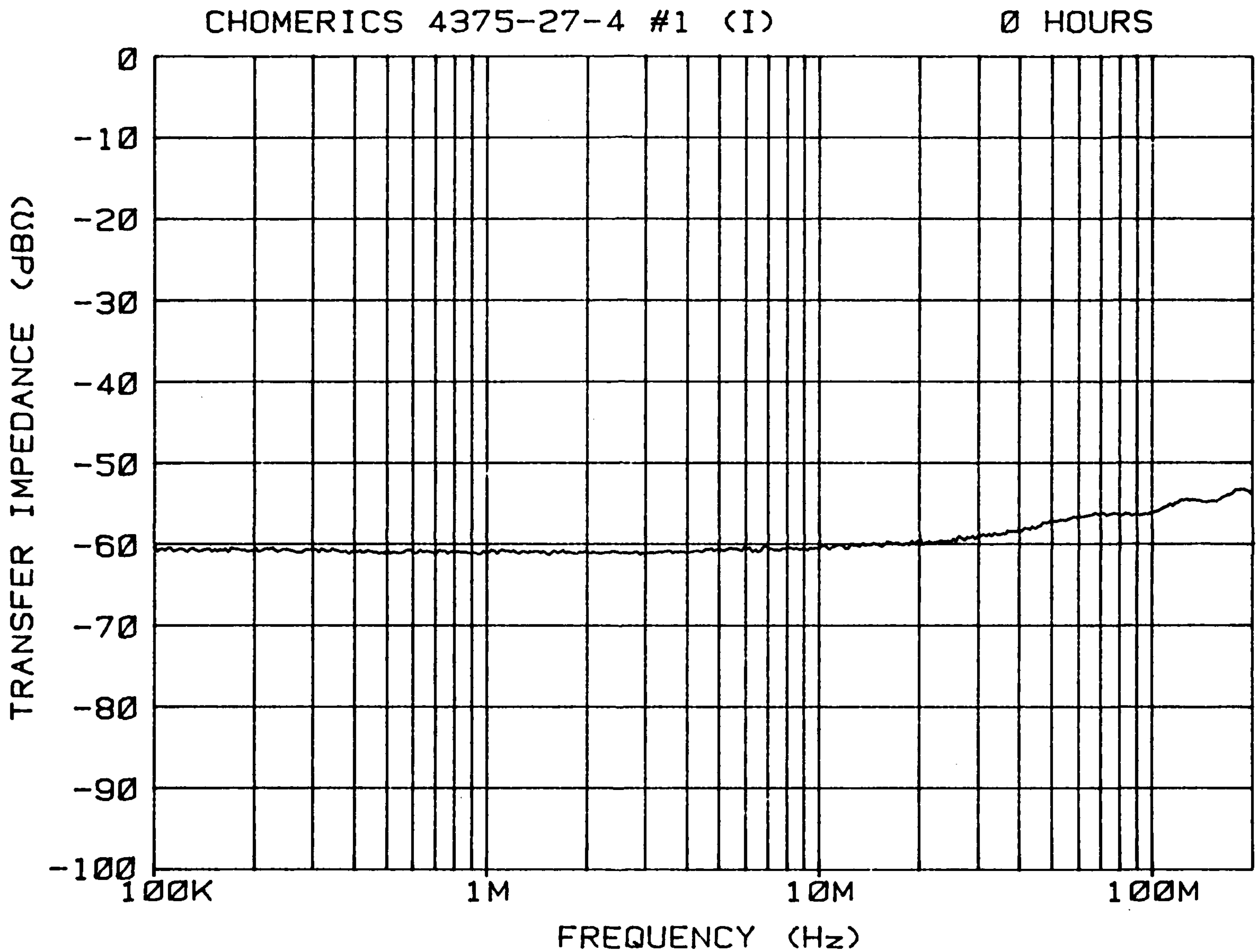


Test Sample D4, t = 2000 Hrs.

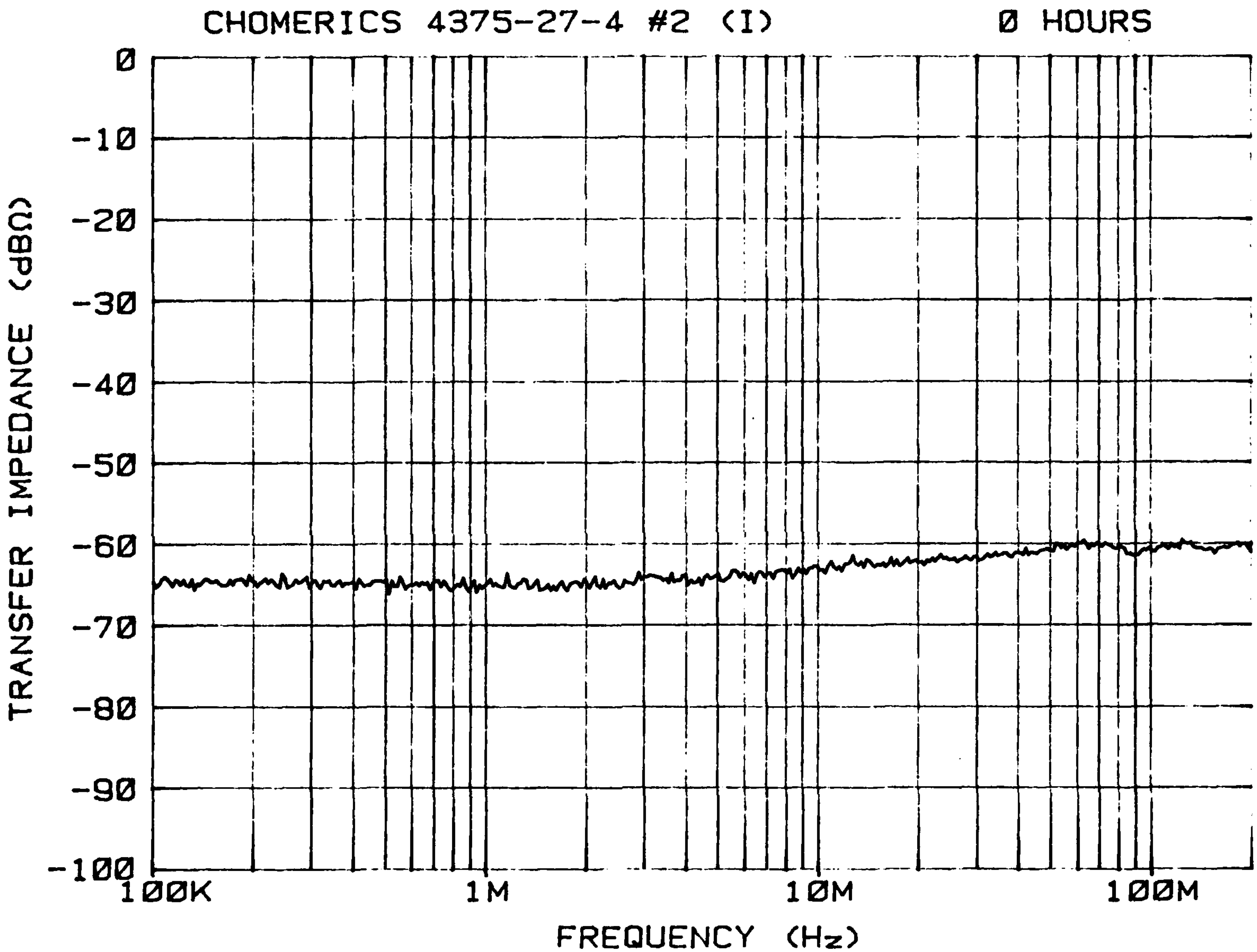
APPENDIX B

TRANSFER IMPEDANCE DATA

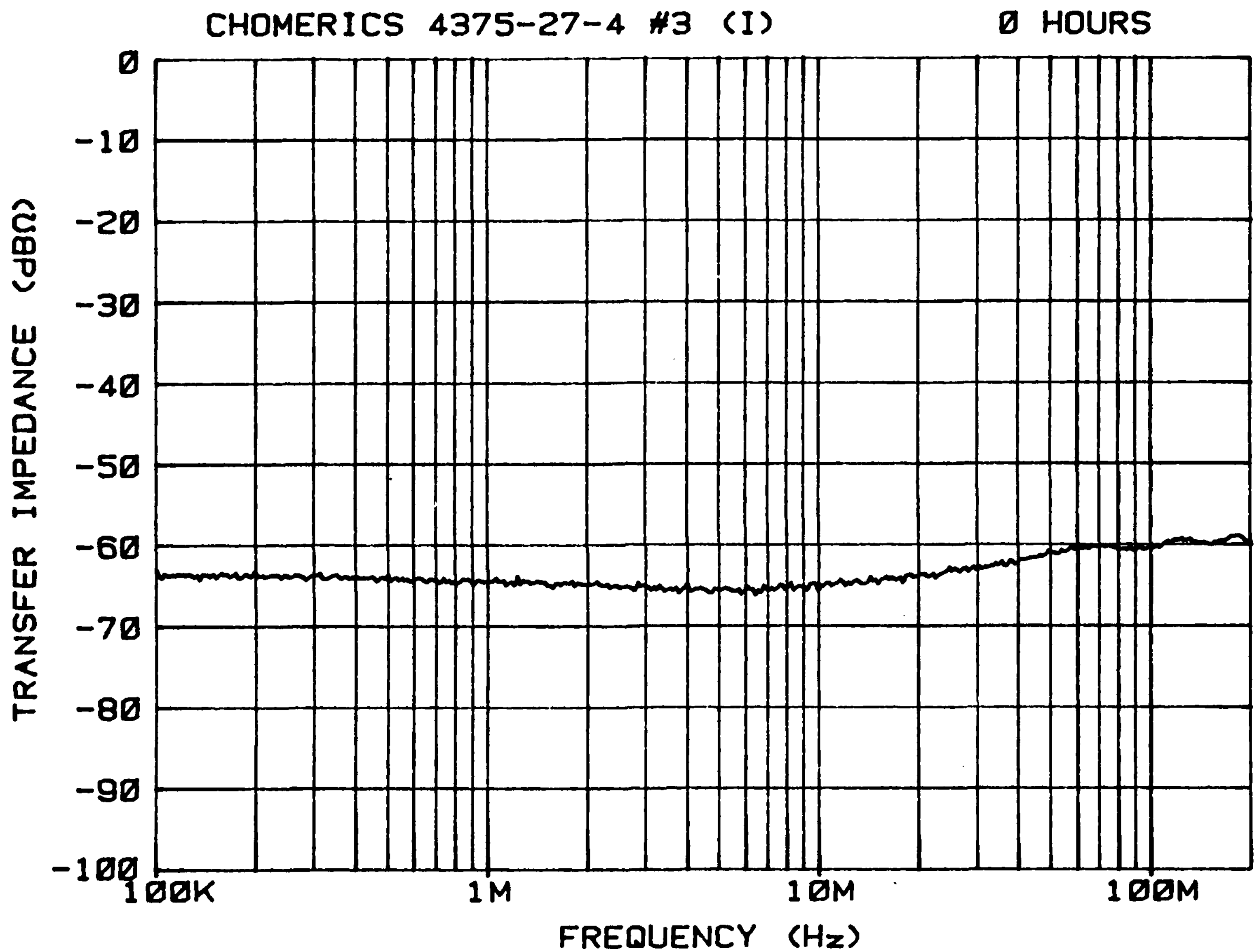
Test Sample A1, 0 Hrs.



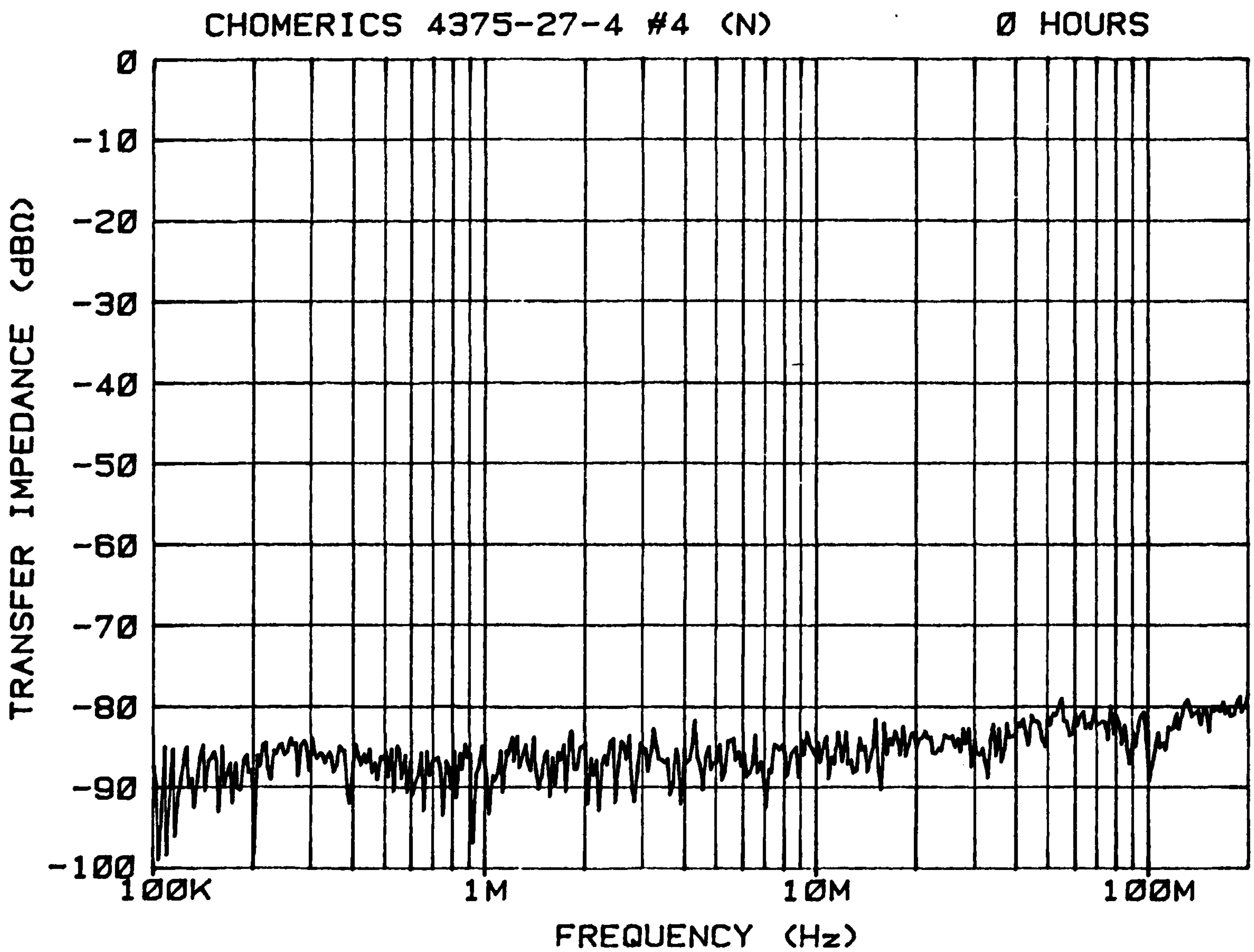
Test Sample A2, 0 Hrs.



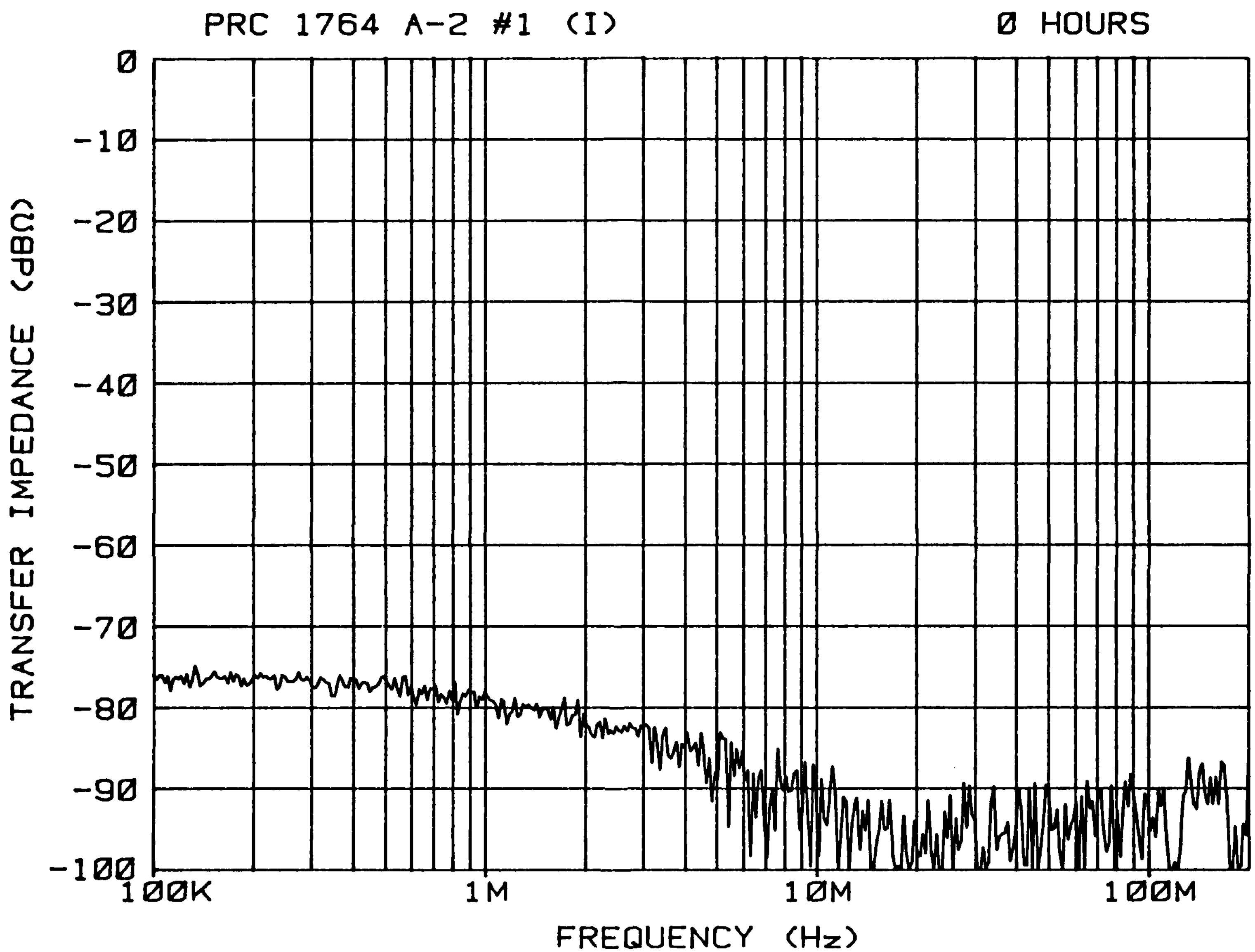
Test Sample A3, 0 Hrs.



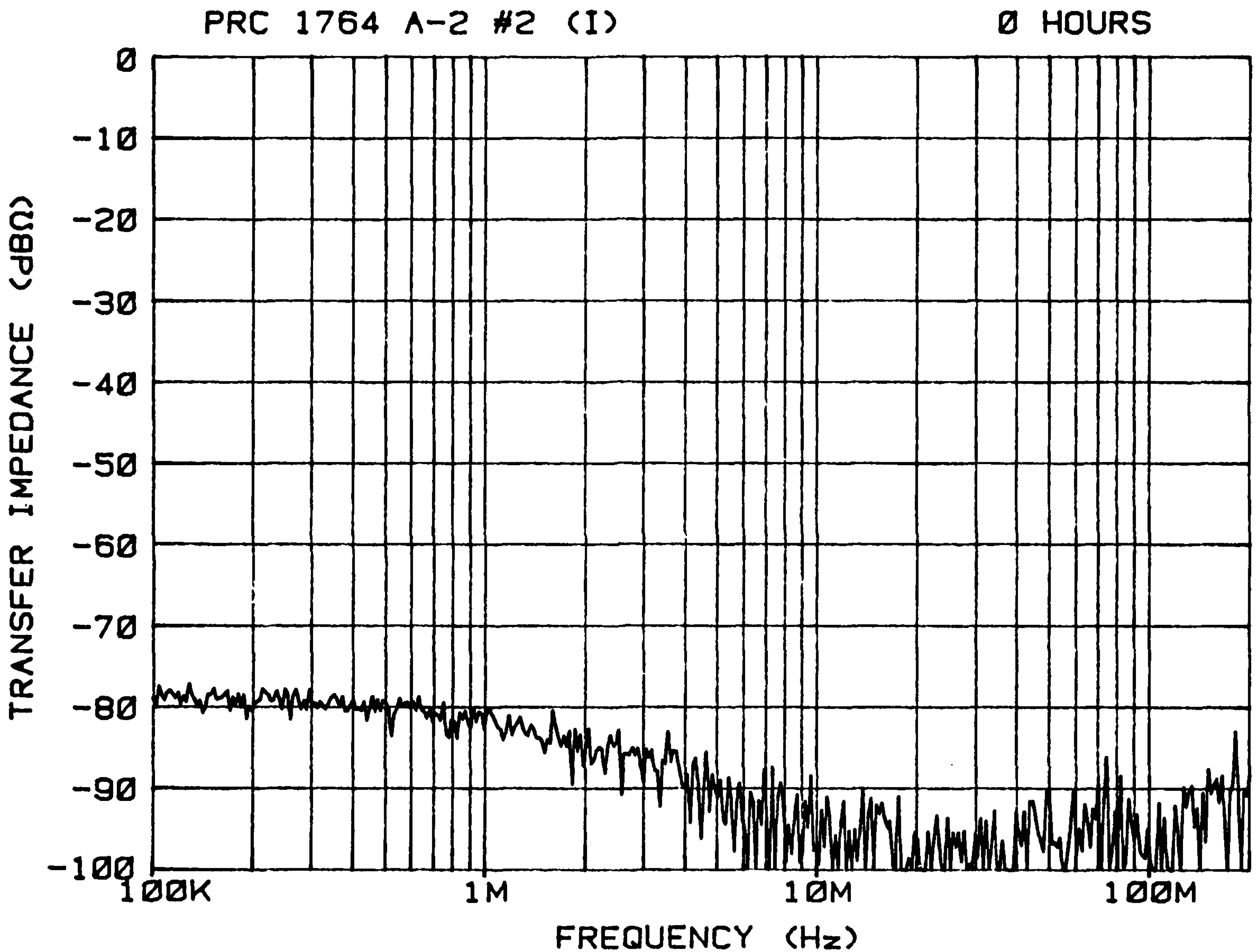
Test Sample A4, 0 Hrs.



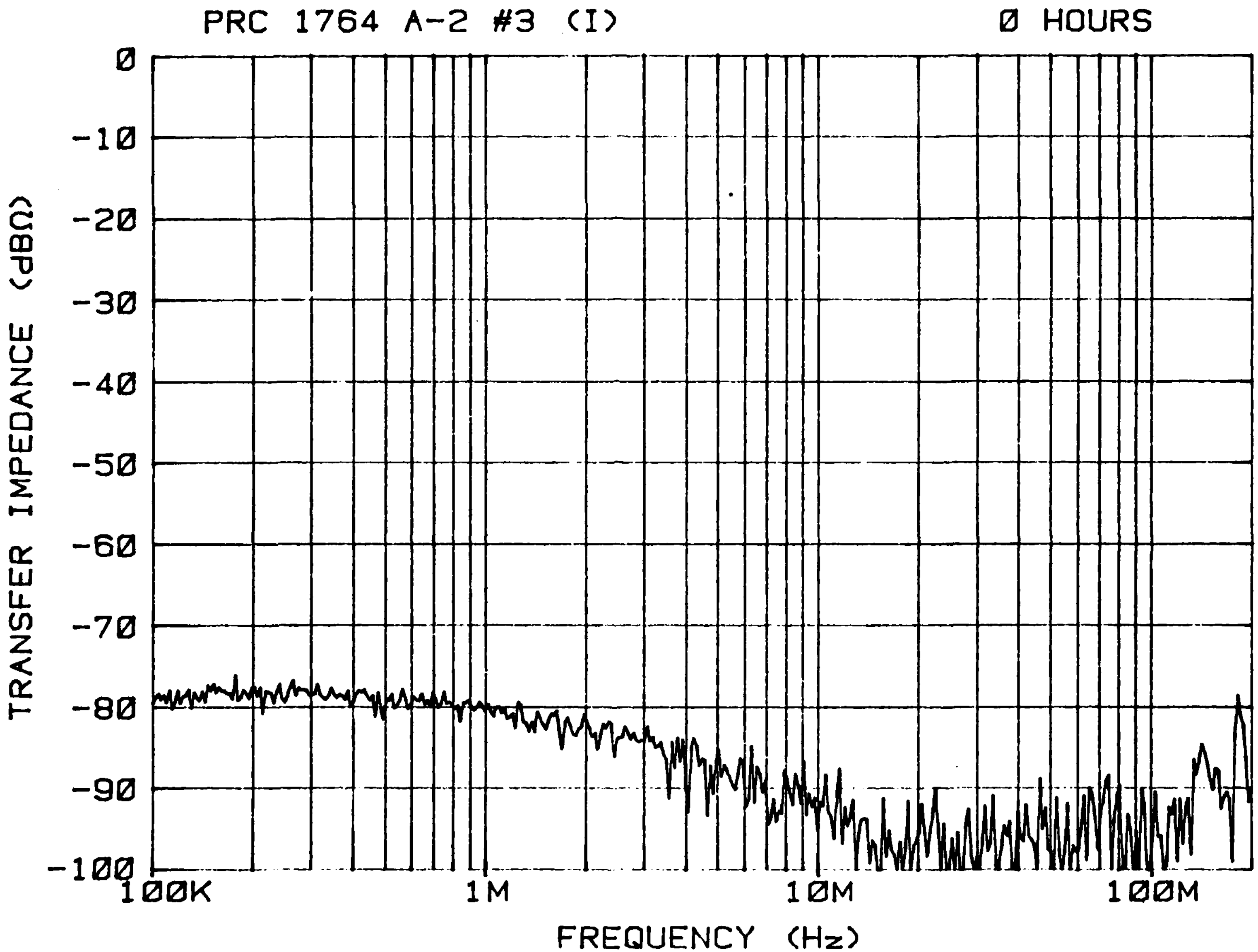
Test Sample A1, 0 Hrs.

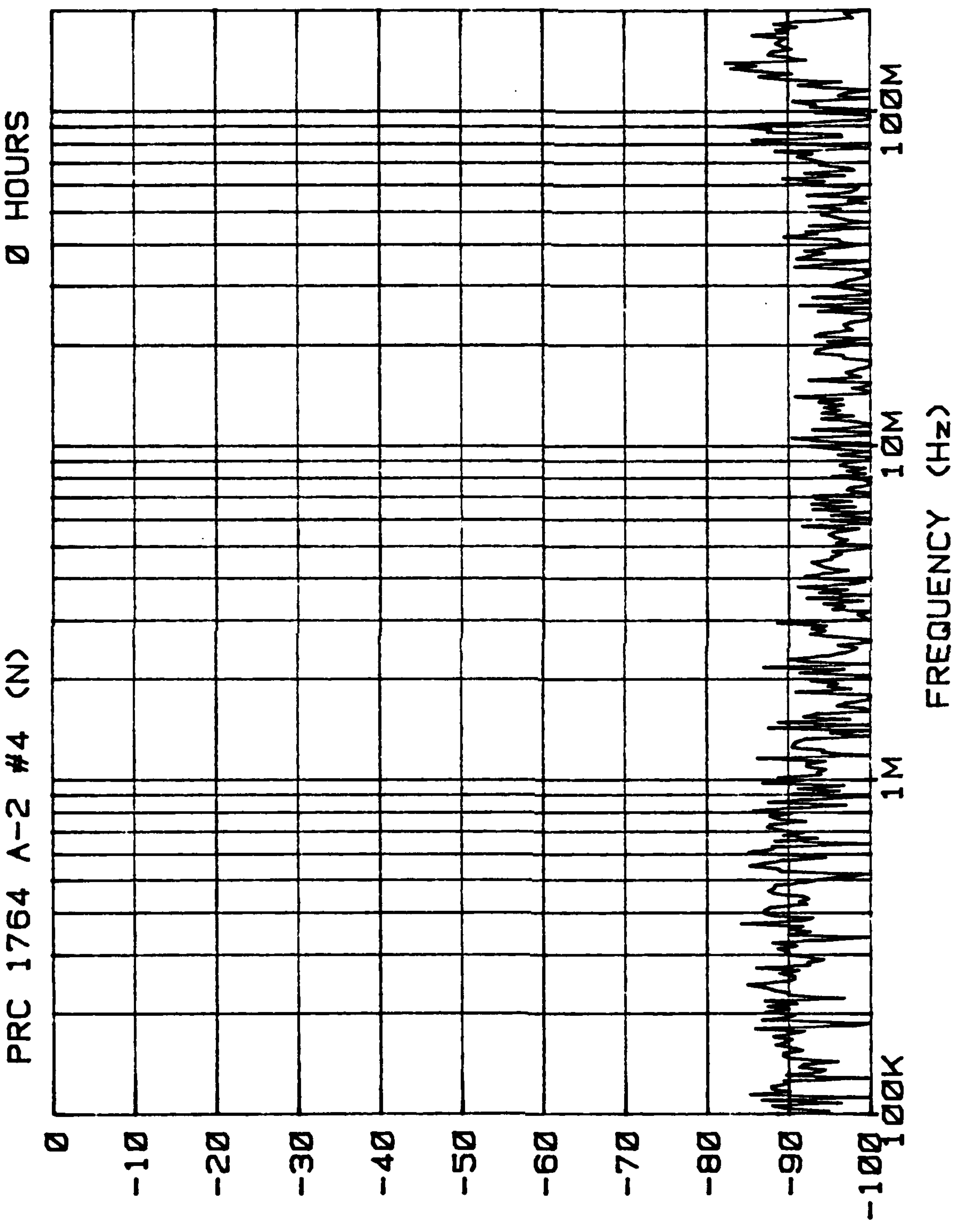


Test Sample A2, 0 Hrs.



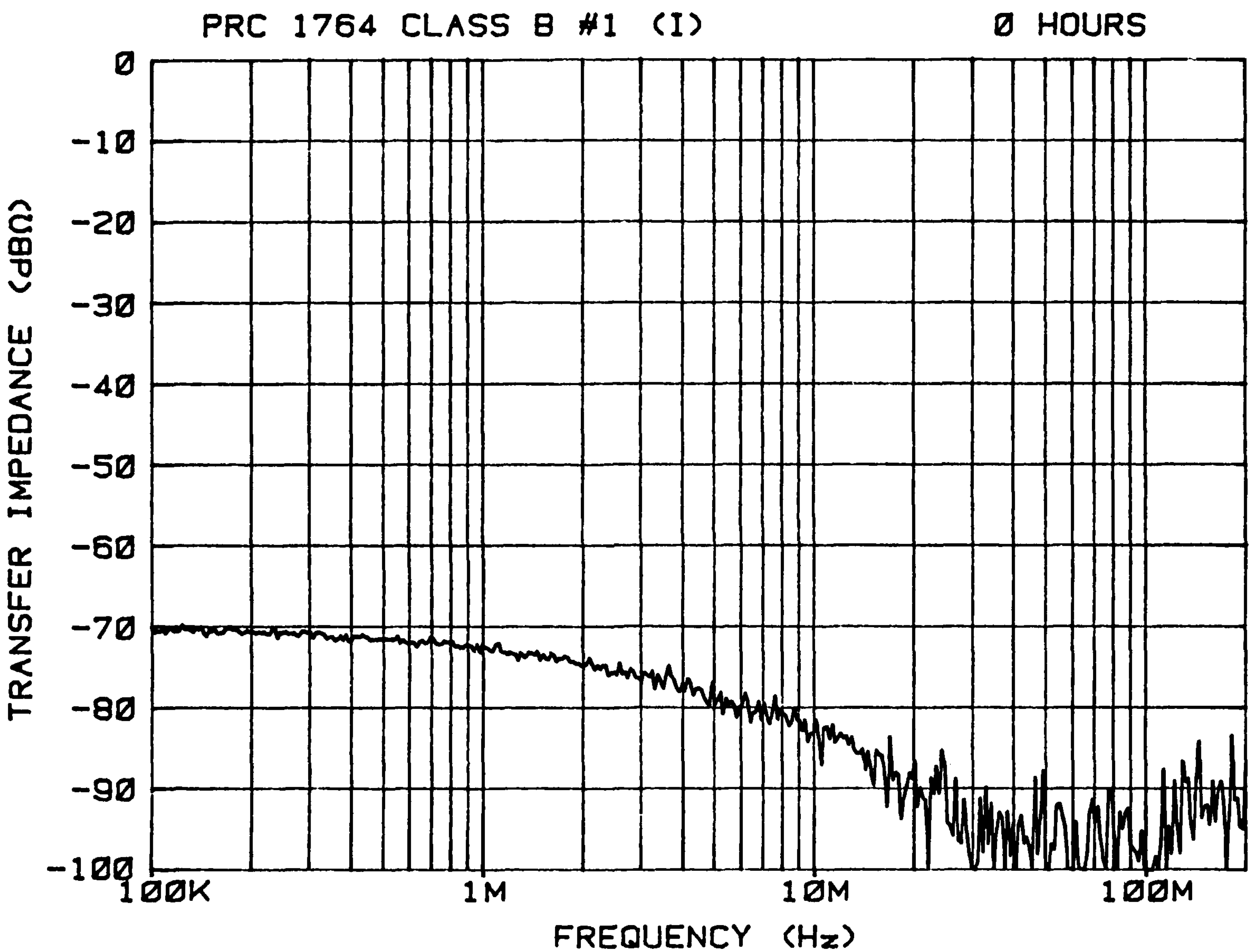
Test Sample A3, 0 Hrs.



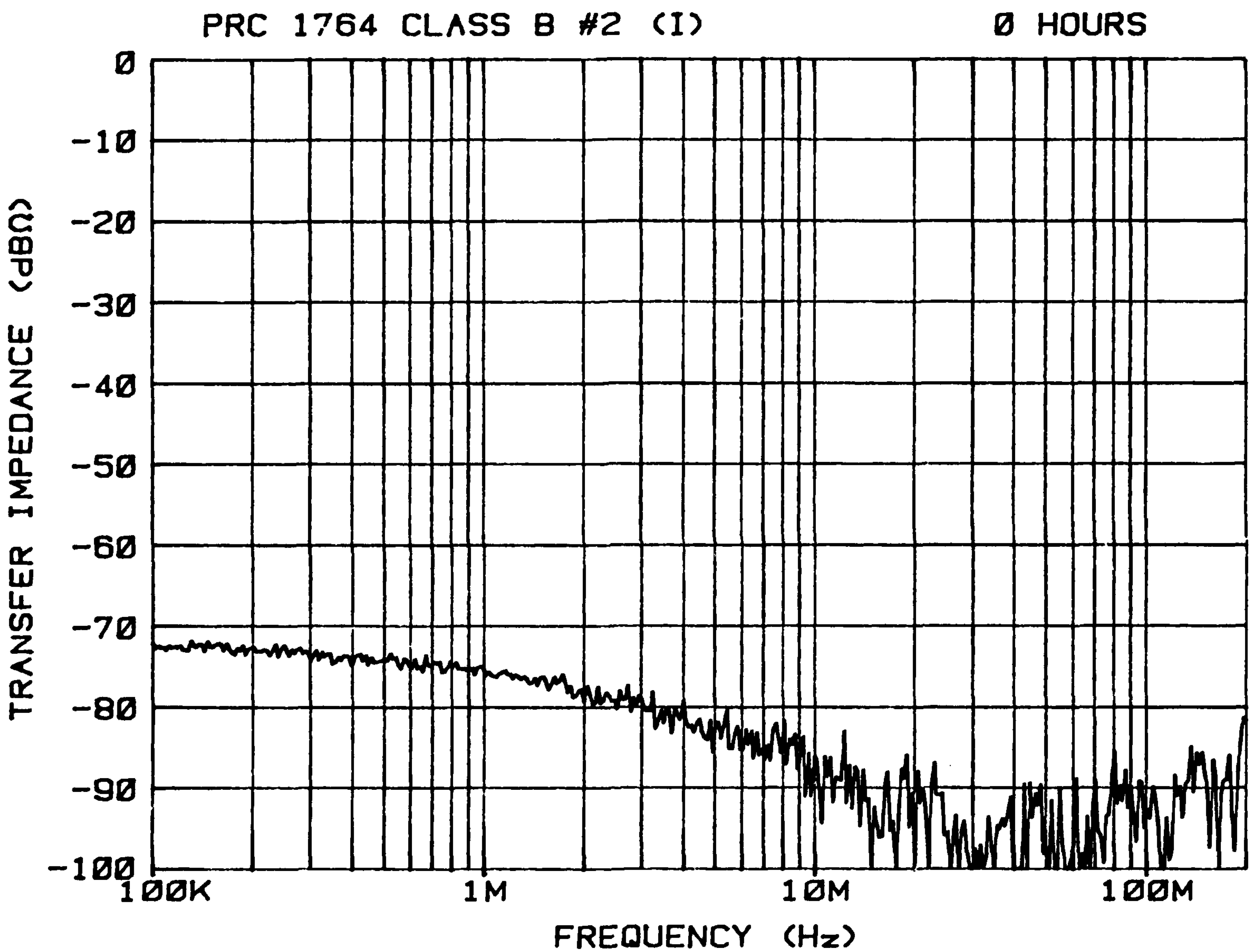


Test Sample A4, 0 Hrs.

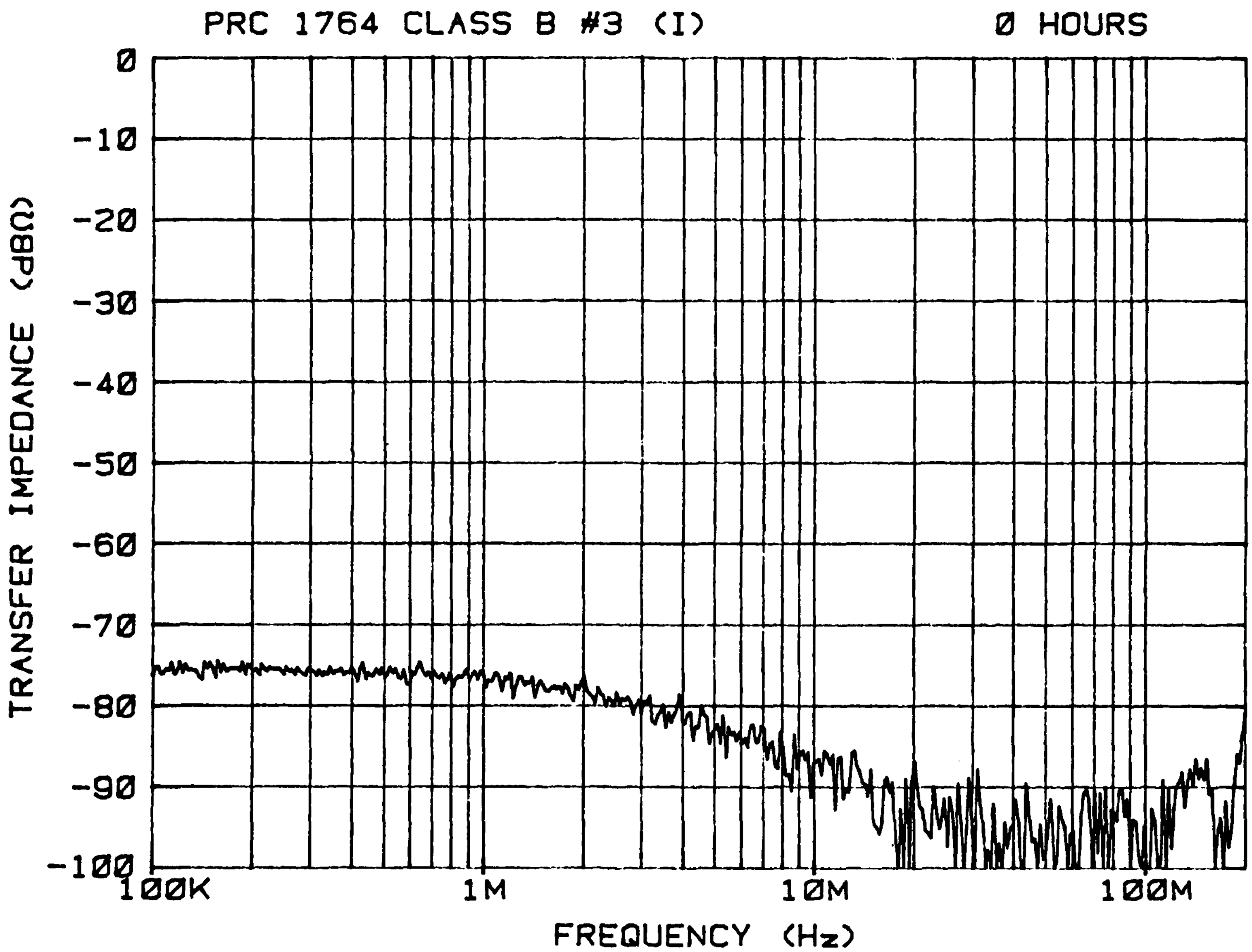
Test Sample A1, 0 Hrs.



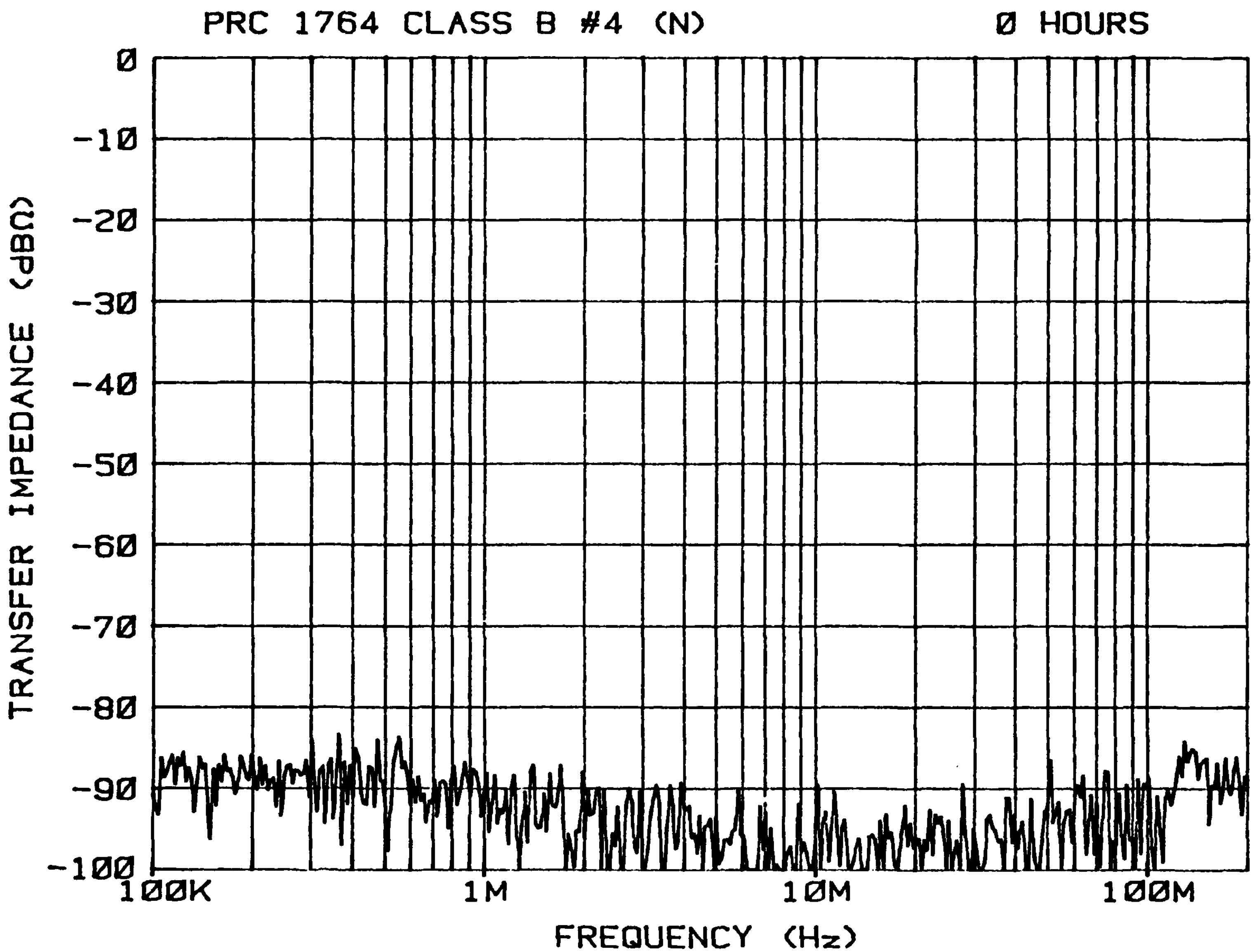
Test Sample A2, 0 Hrs.



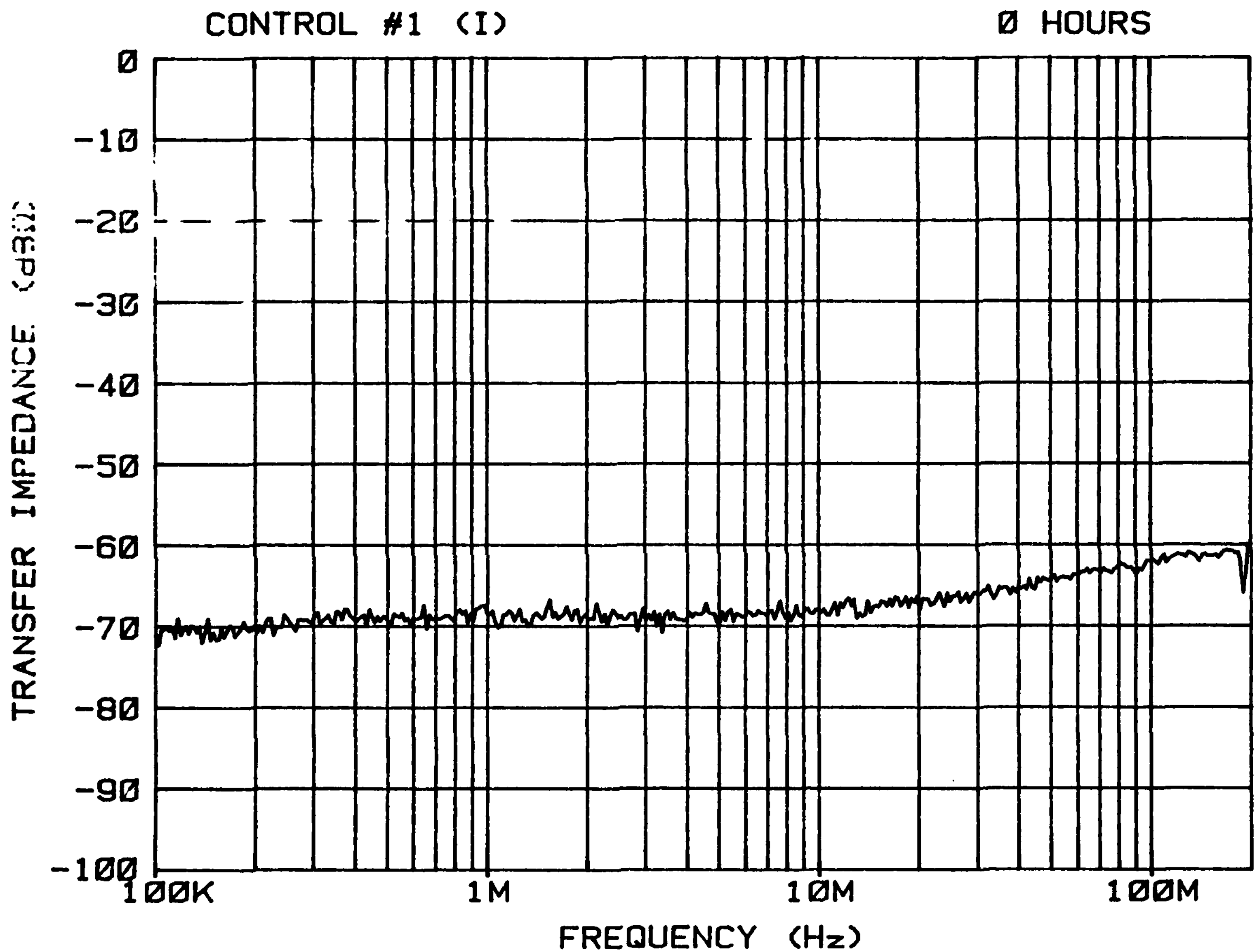
Test Sample A3, 0 Hrs.



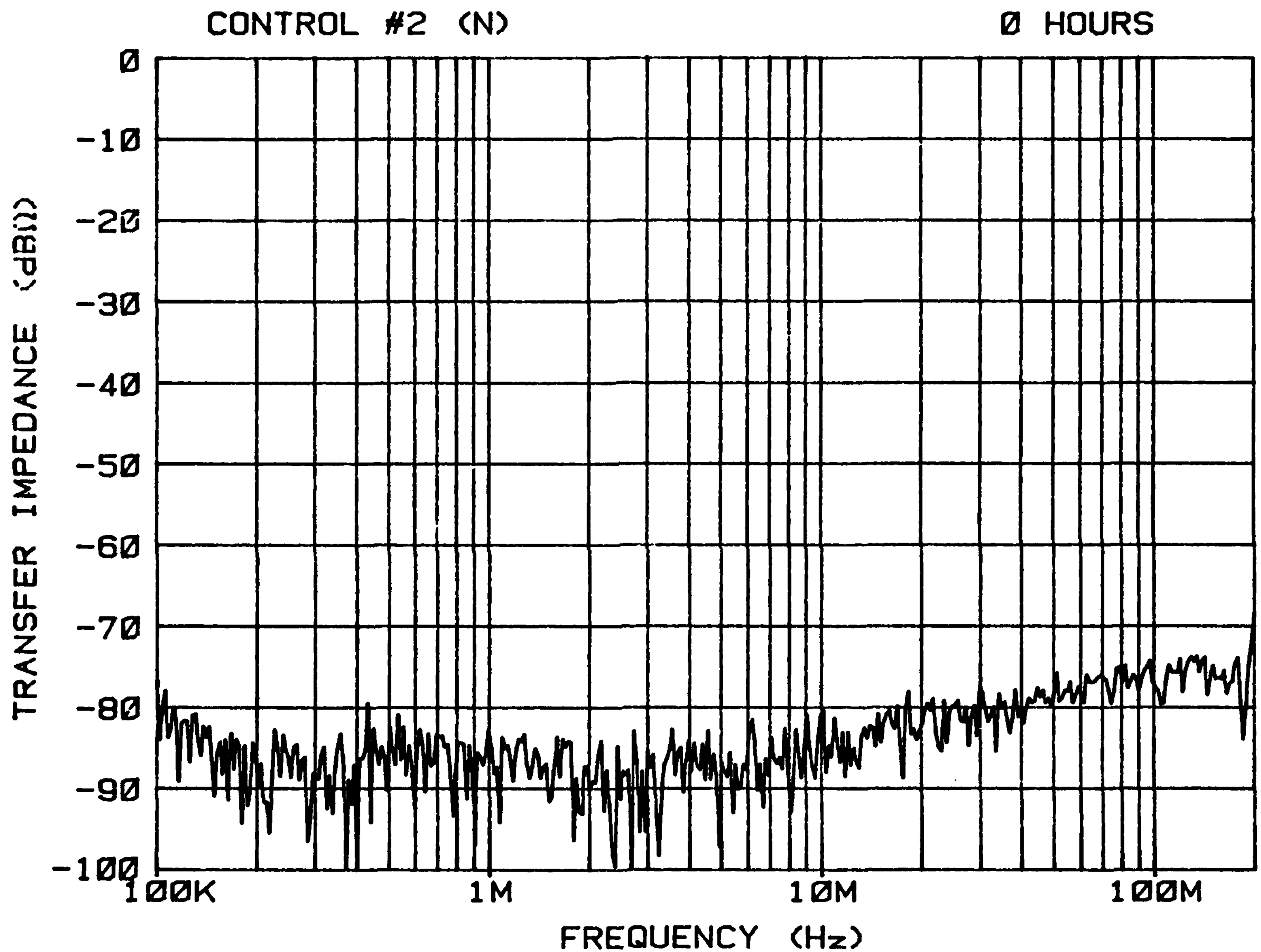
Test Sample A4, 0 Hrs.



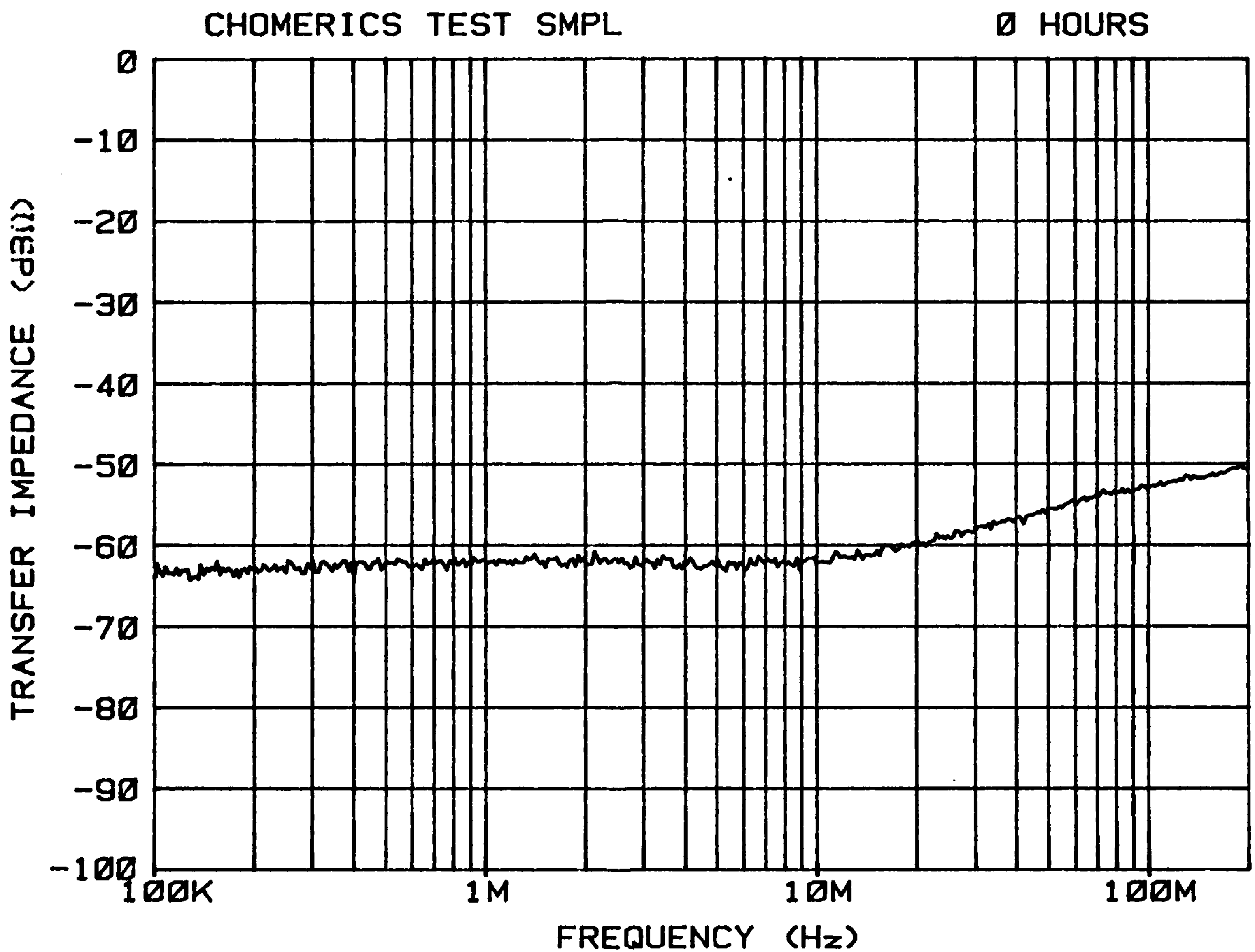
Test Sample B1, 0 Hrs.



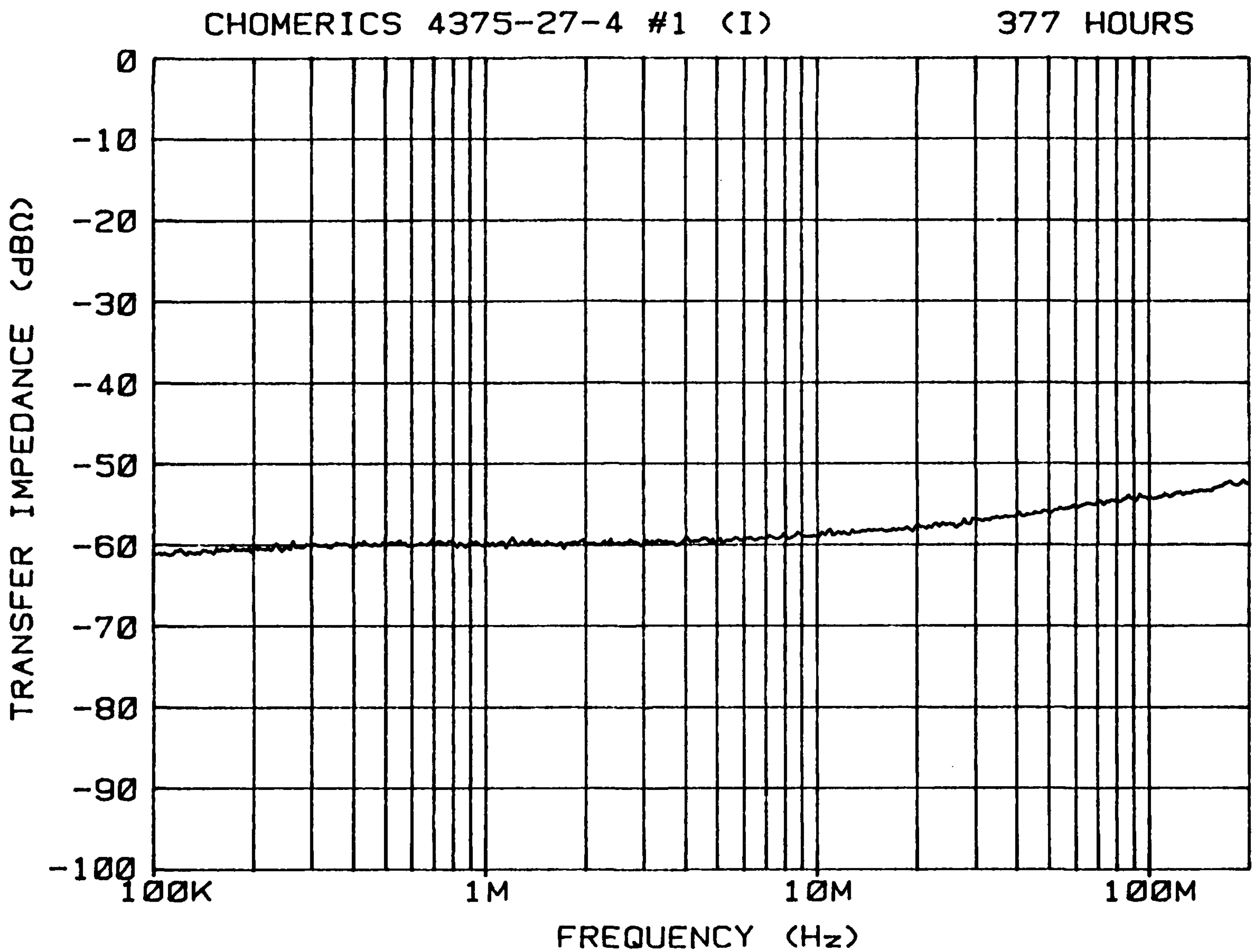
Test Sample B2, 0 Hrs.



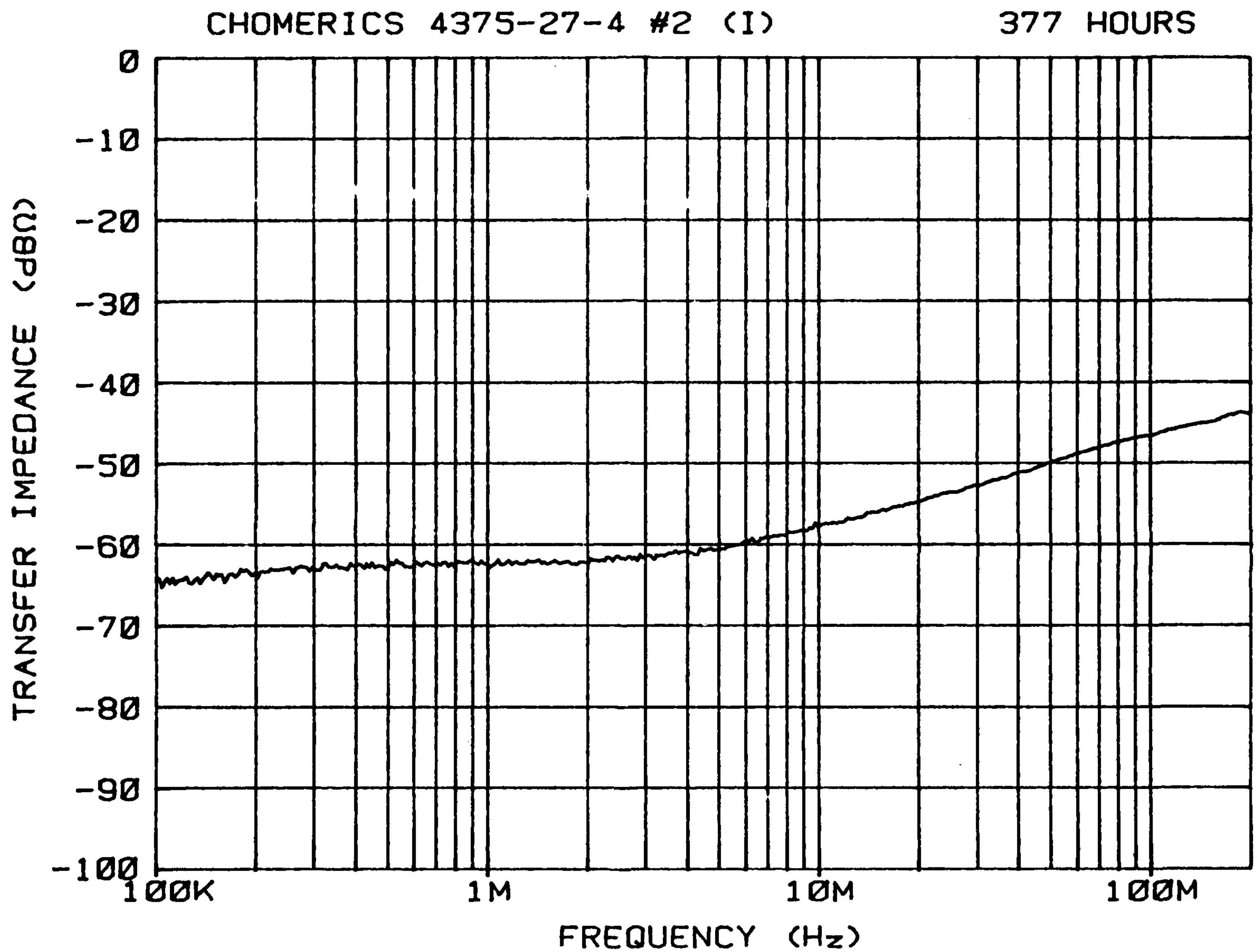
Test Sample B3, 0 Hrs.



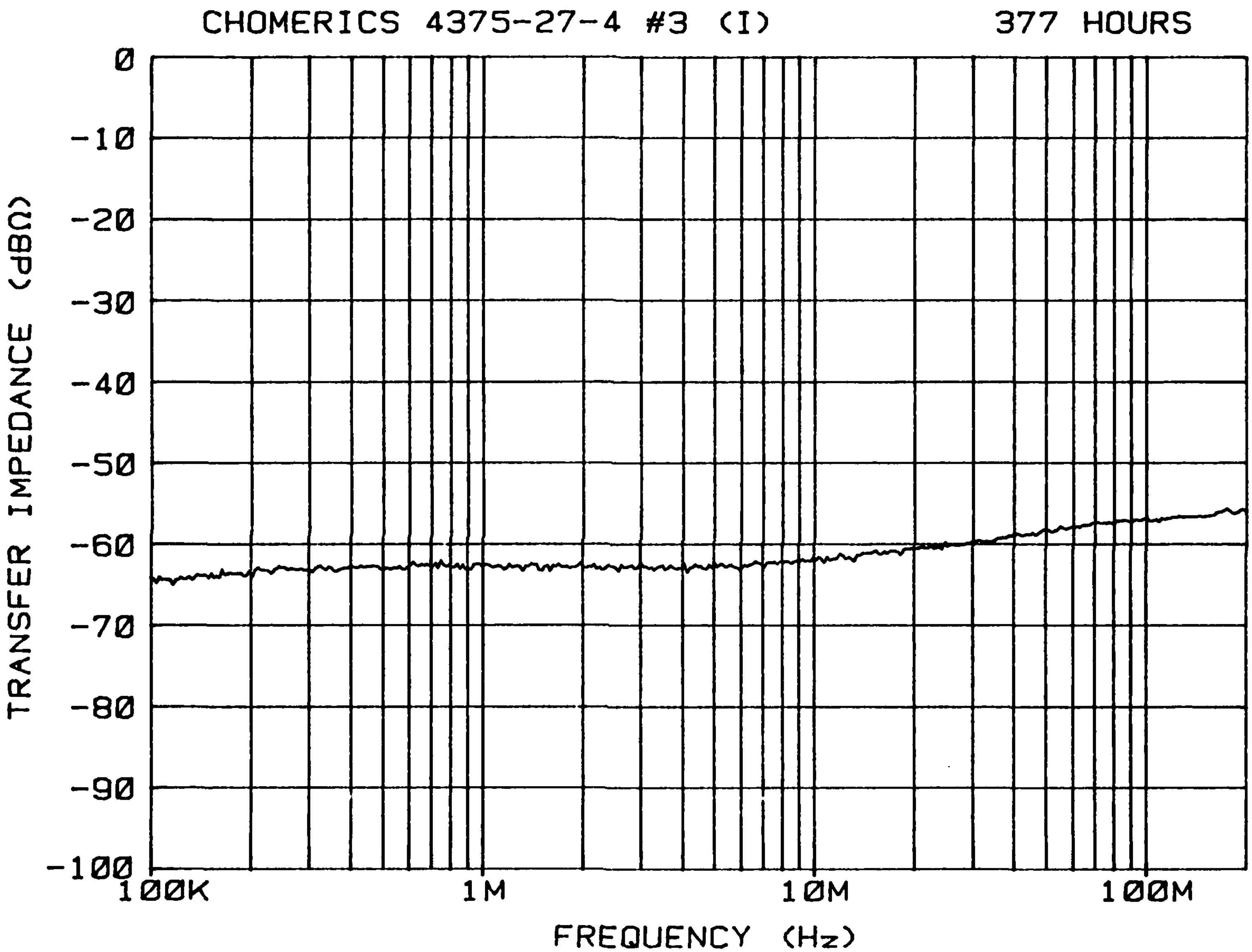
Test Sample Al, 377 Hrs.



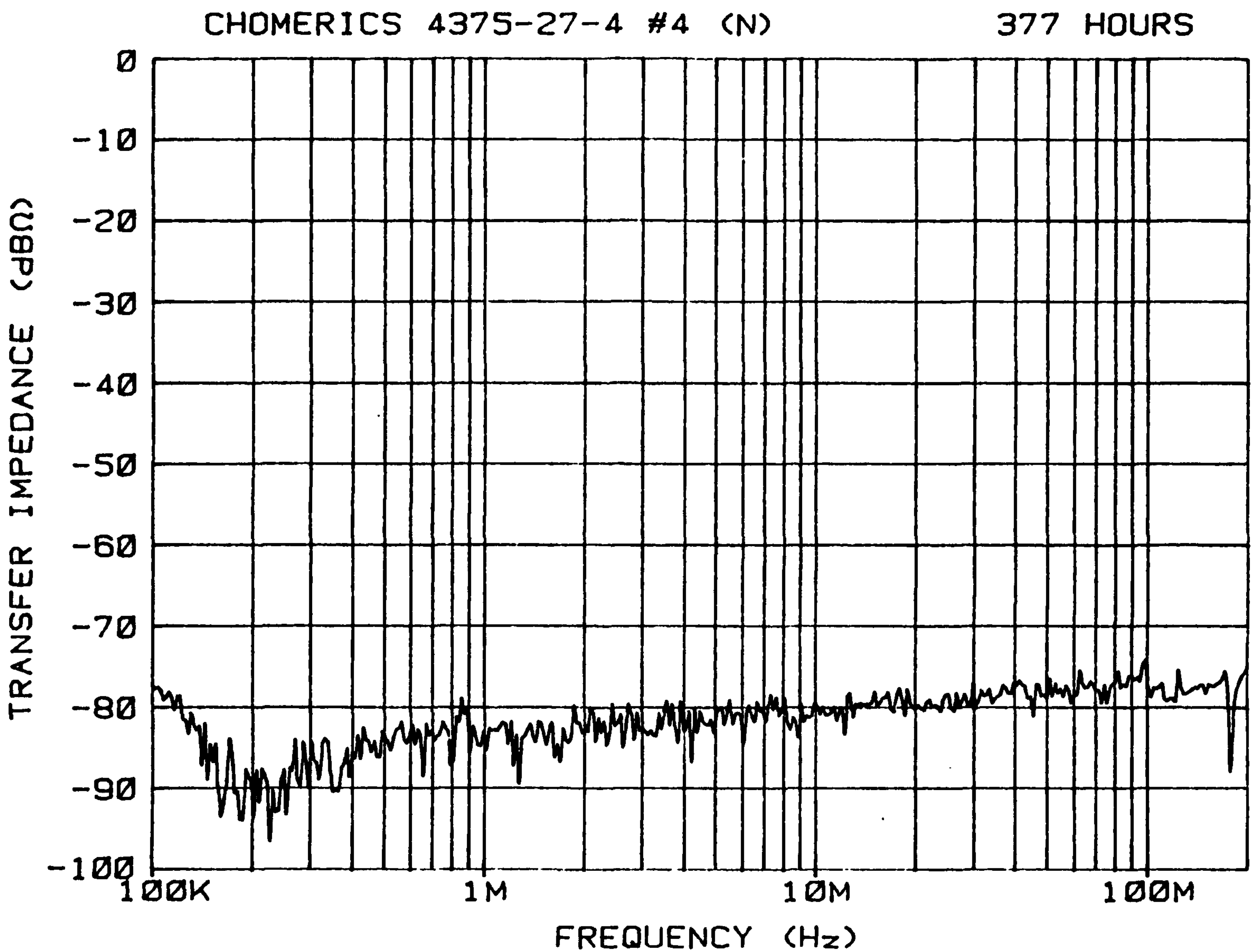
Test Sample A2, 0 Hrs.



Test Sample A3, 377 Hrs.

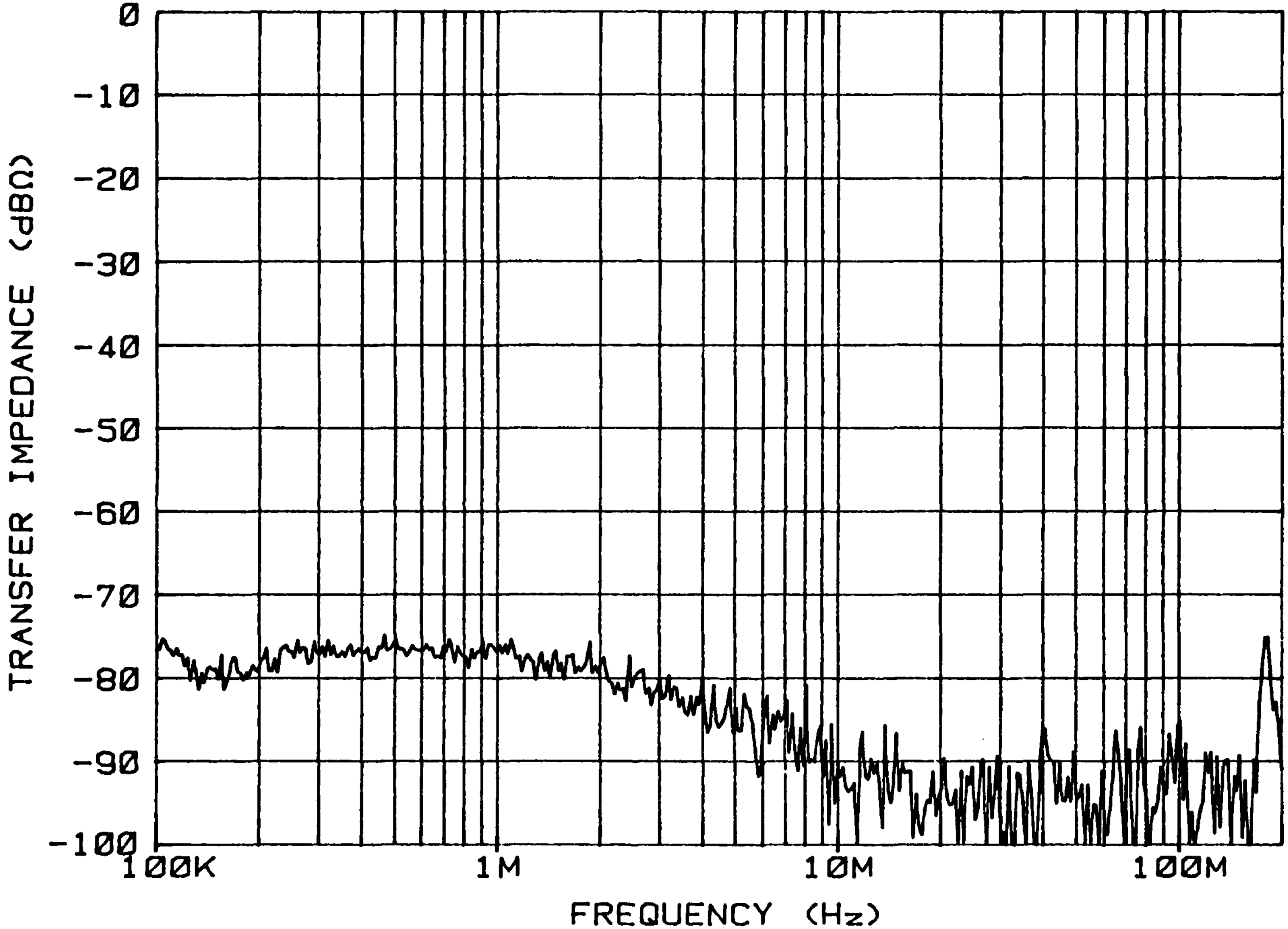


Test Sample A4, 377 Hrs.

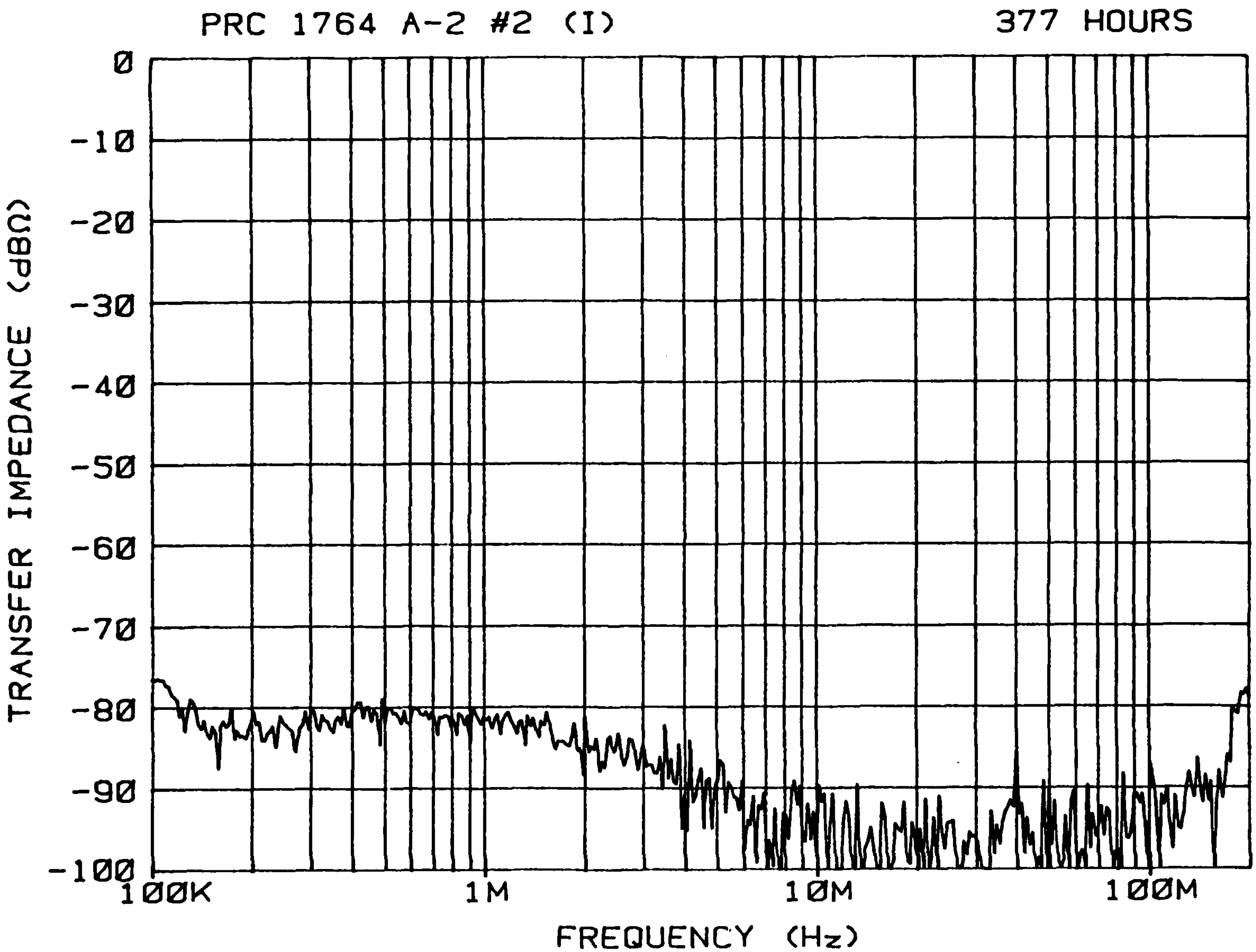


Test Sample C1, 377 Hrs.

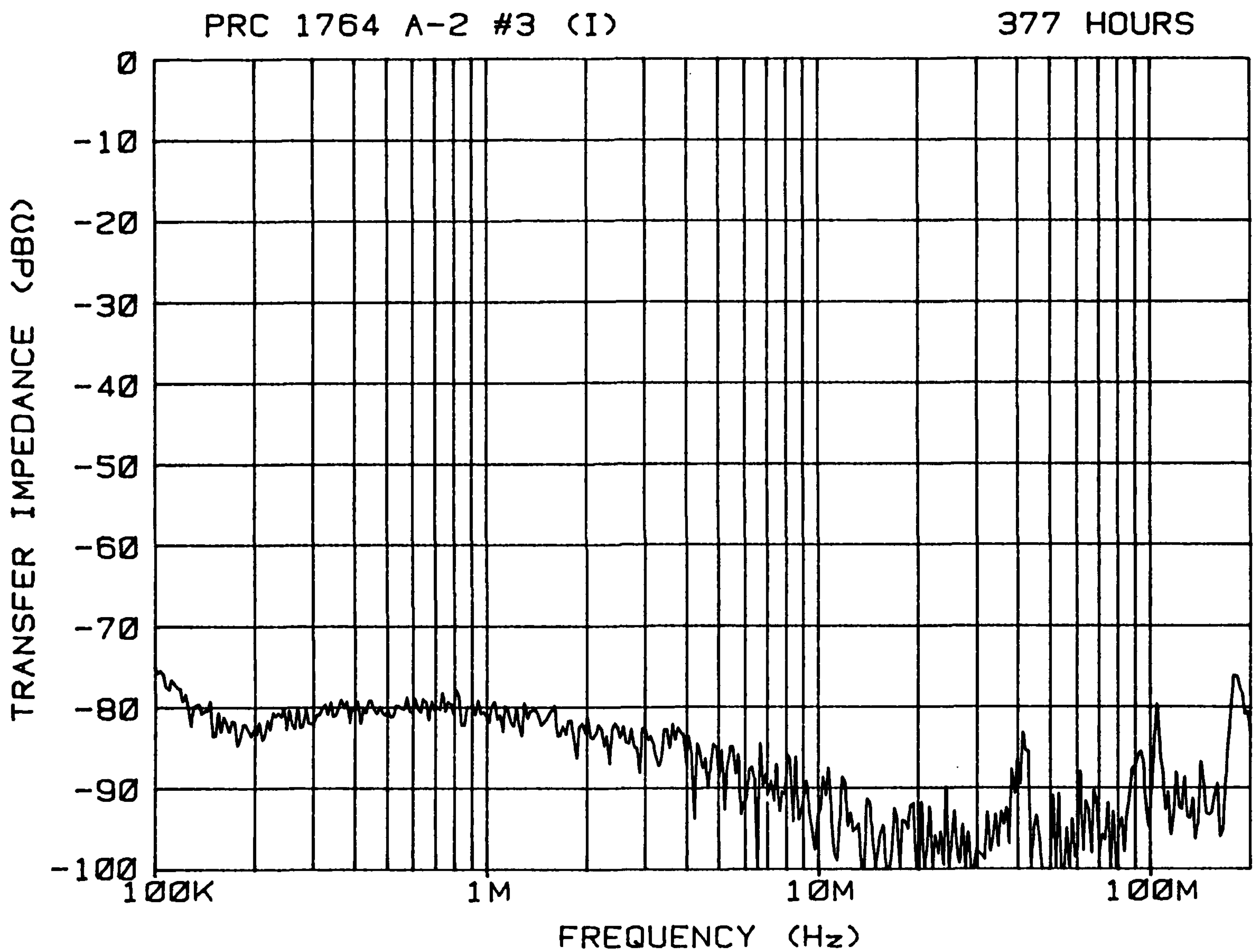
PRC 1764 A-2 #1 (I) 377 HOURS

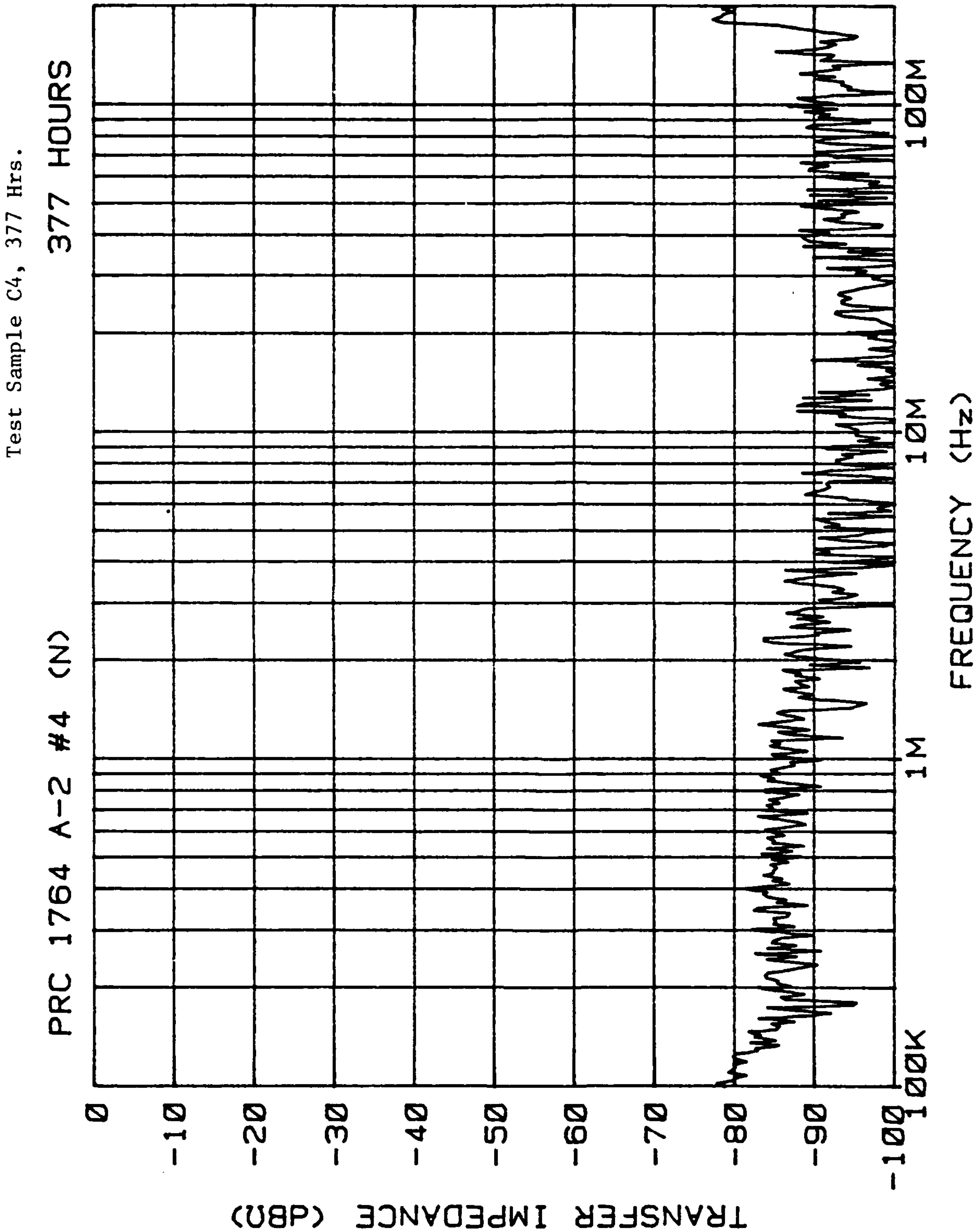


Test Sample C2, 377 Hrs.

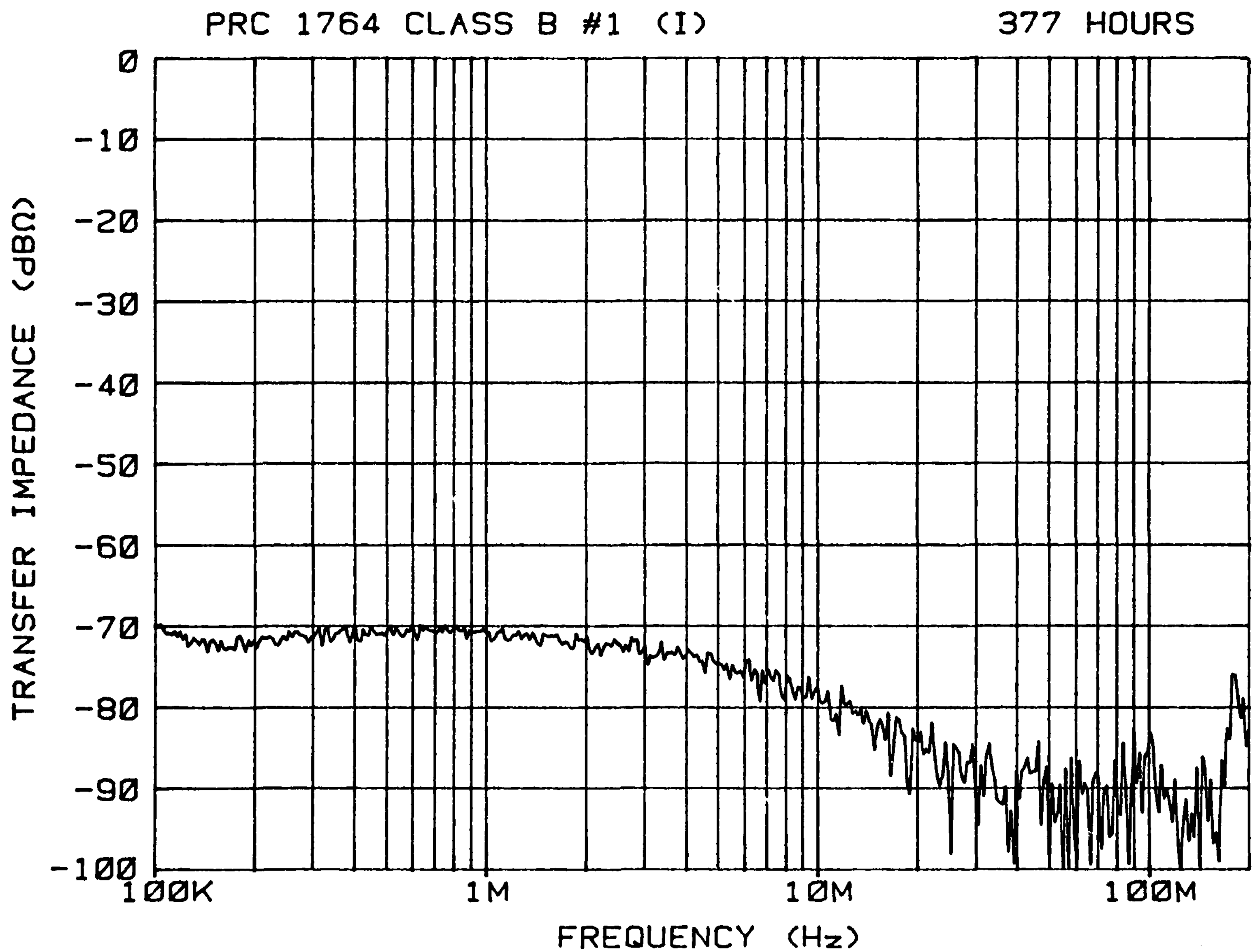


Test Sample C3, 377 Hrs.

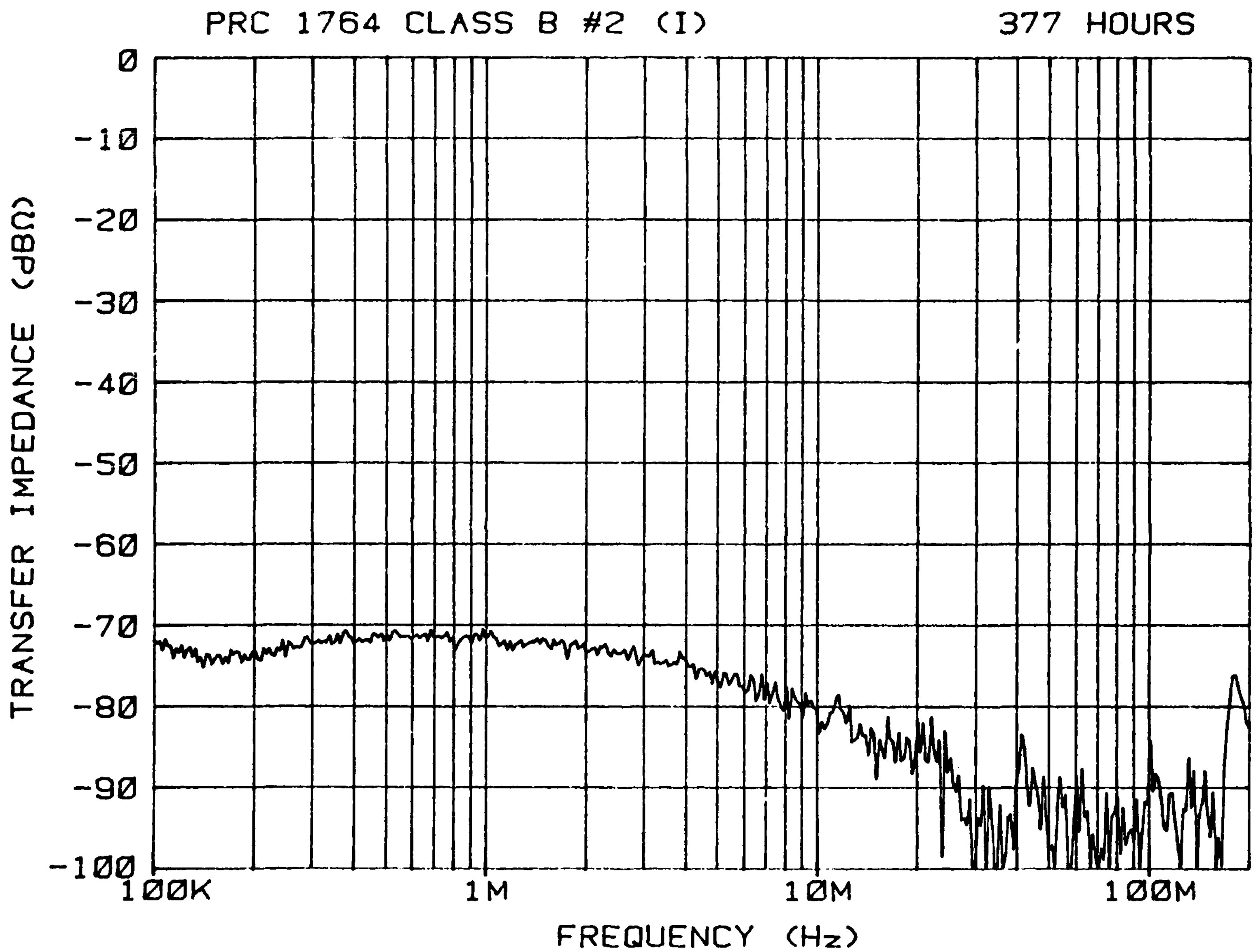



Test Sample C4, 377 Hrs.
PRC 1764 A-2 #4 (N)
377 HOURS
TRANSFER IMPEDANCE (dBΩ)
FREQUENCY (Hz)
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
100K
1M
10M
100M

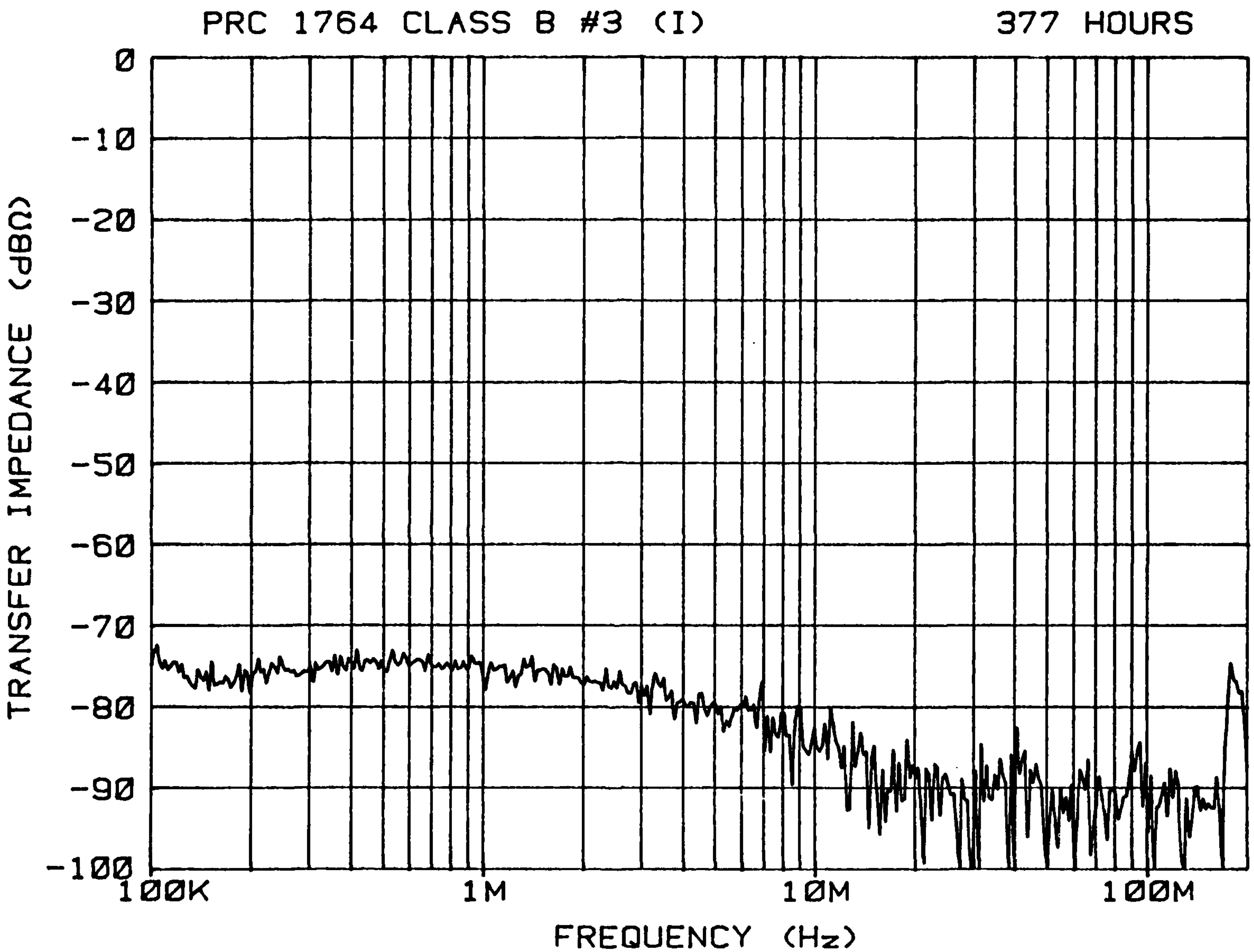
Test Sample D1, 377 Hrs.



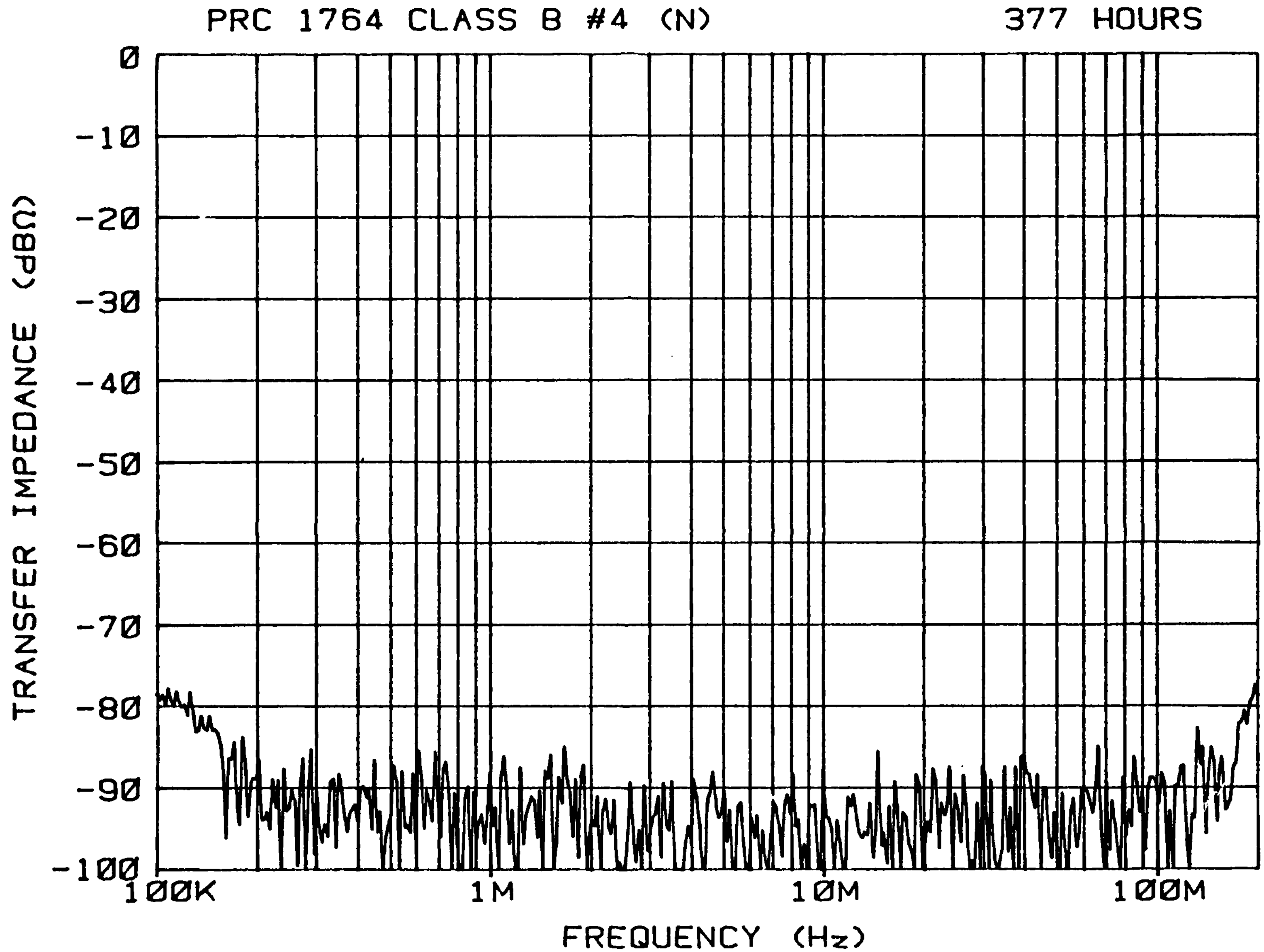
Test Sample D2, 377 Hrs.



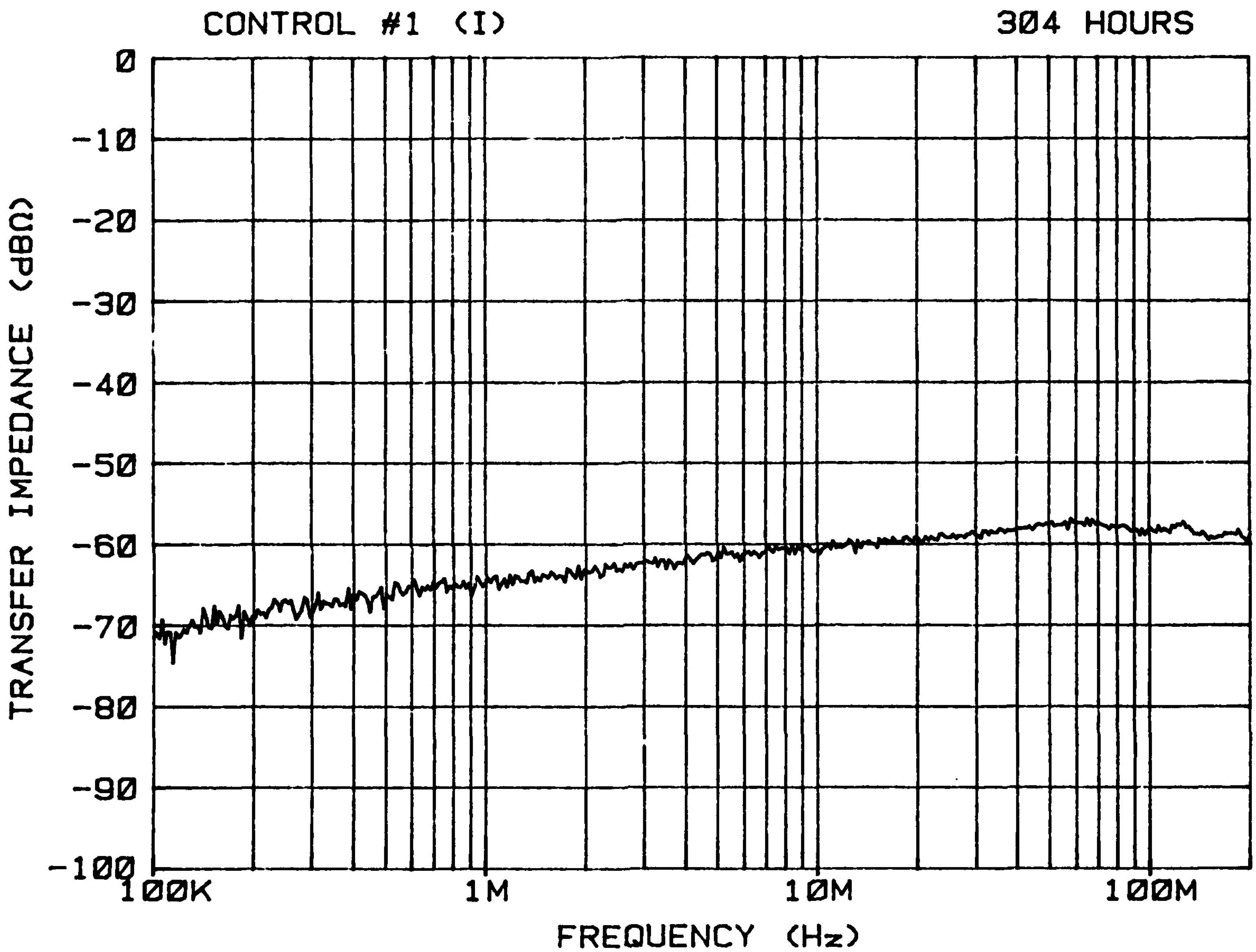
Test Sample D3, 377 Hrs.



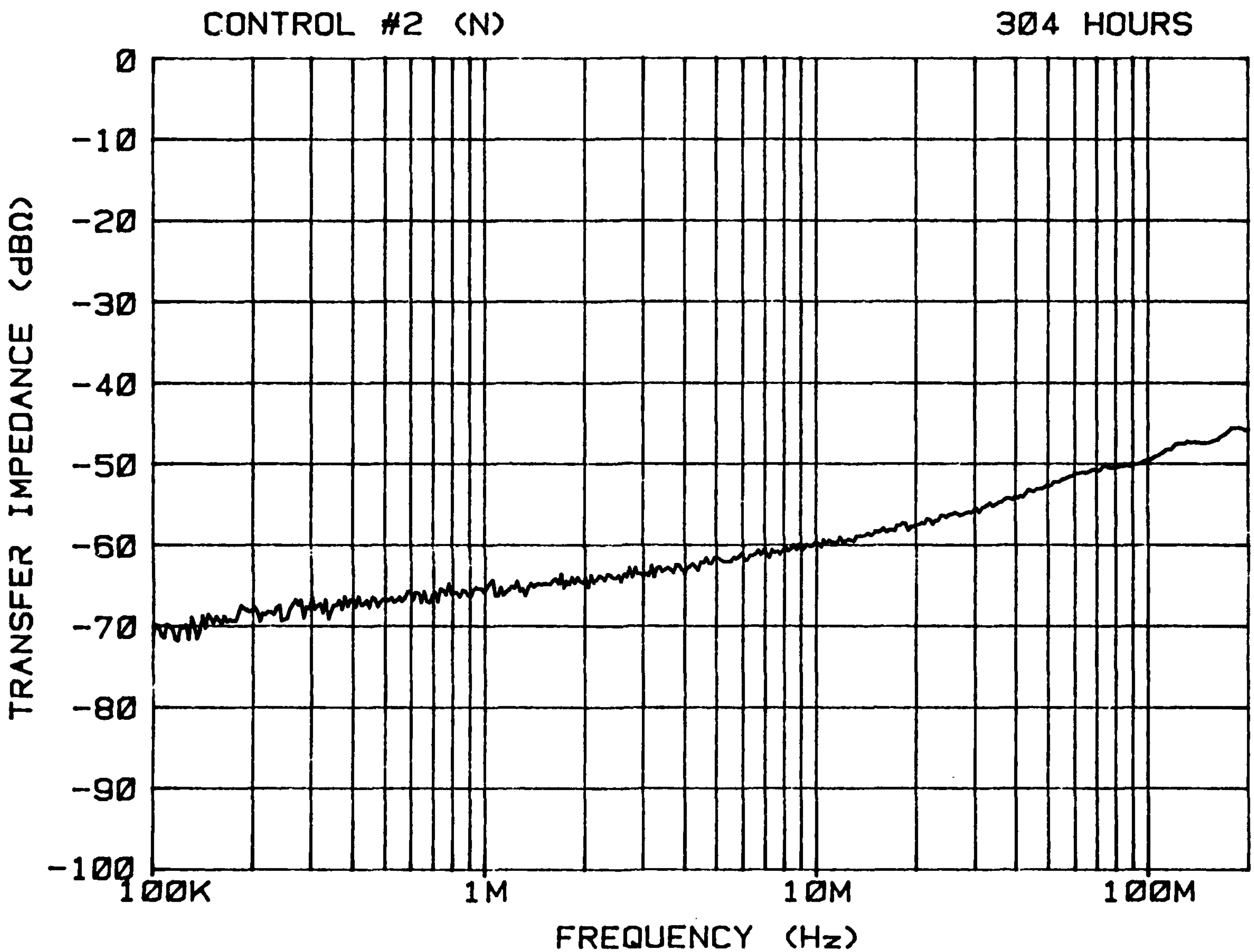
Test Sample D4, 377 Hrs.



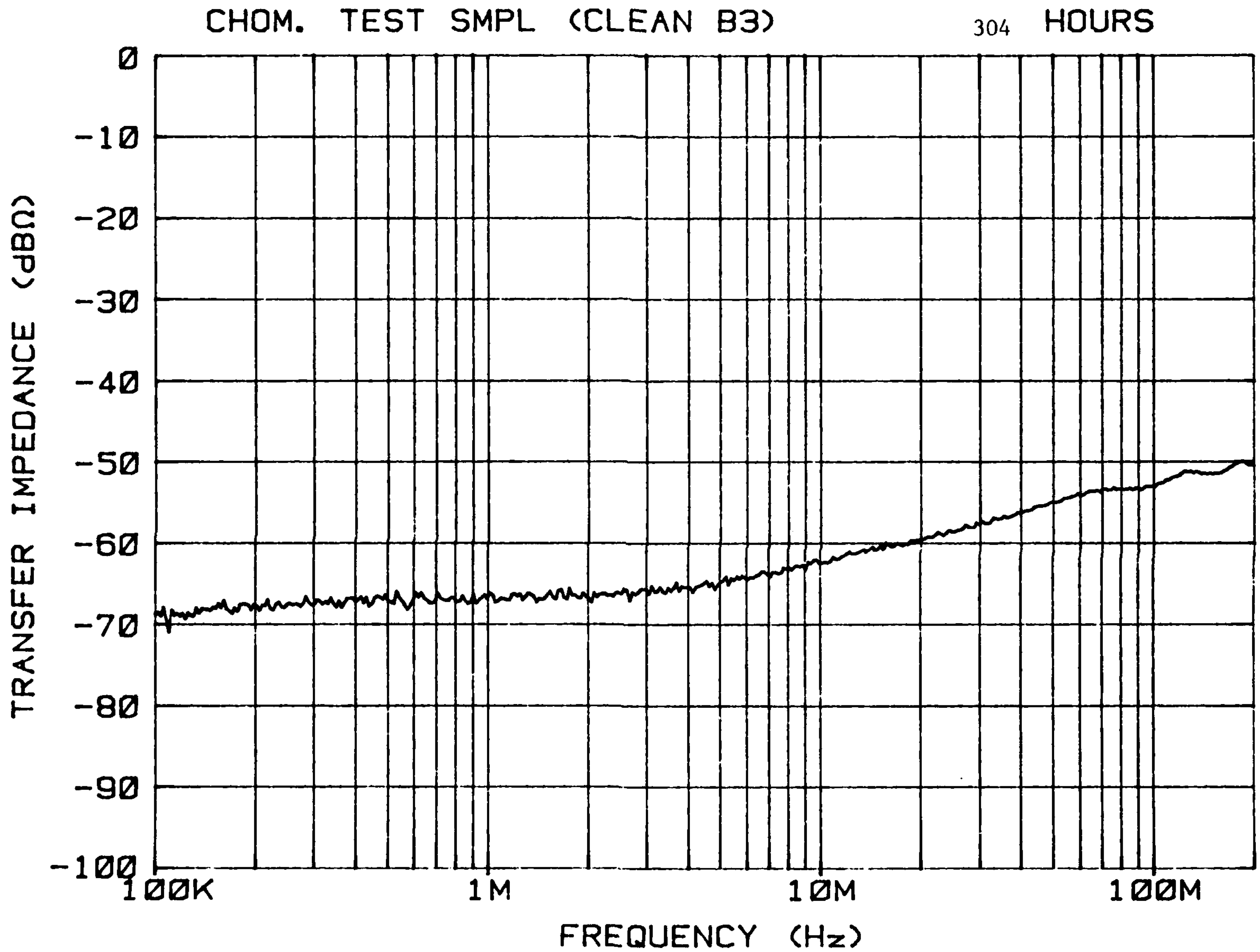
Test Sample B1, 304 Hrs.



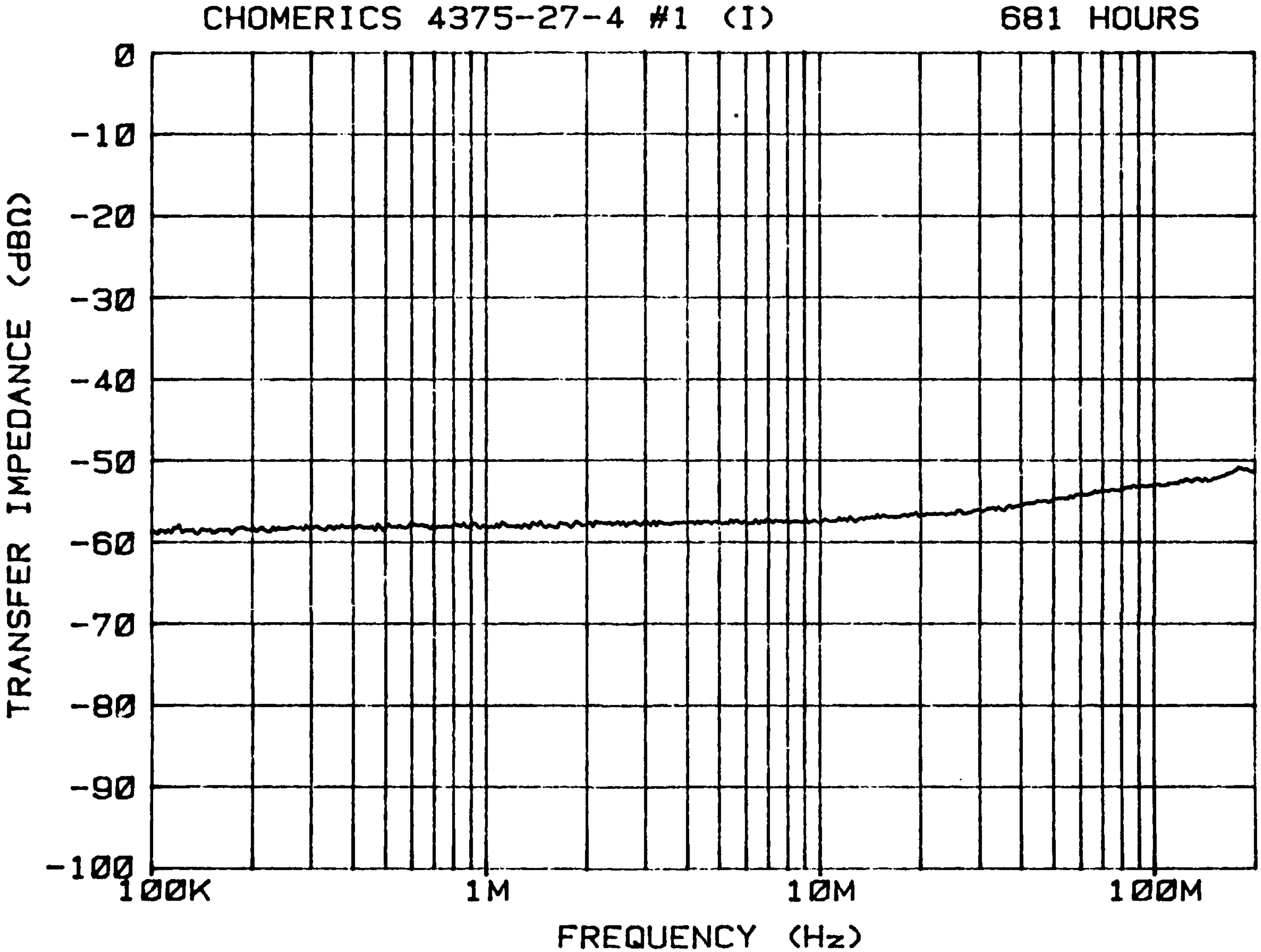
Test Sample B2, 304 Hrs.



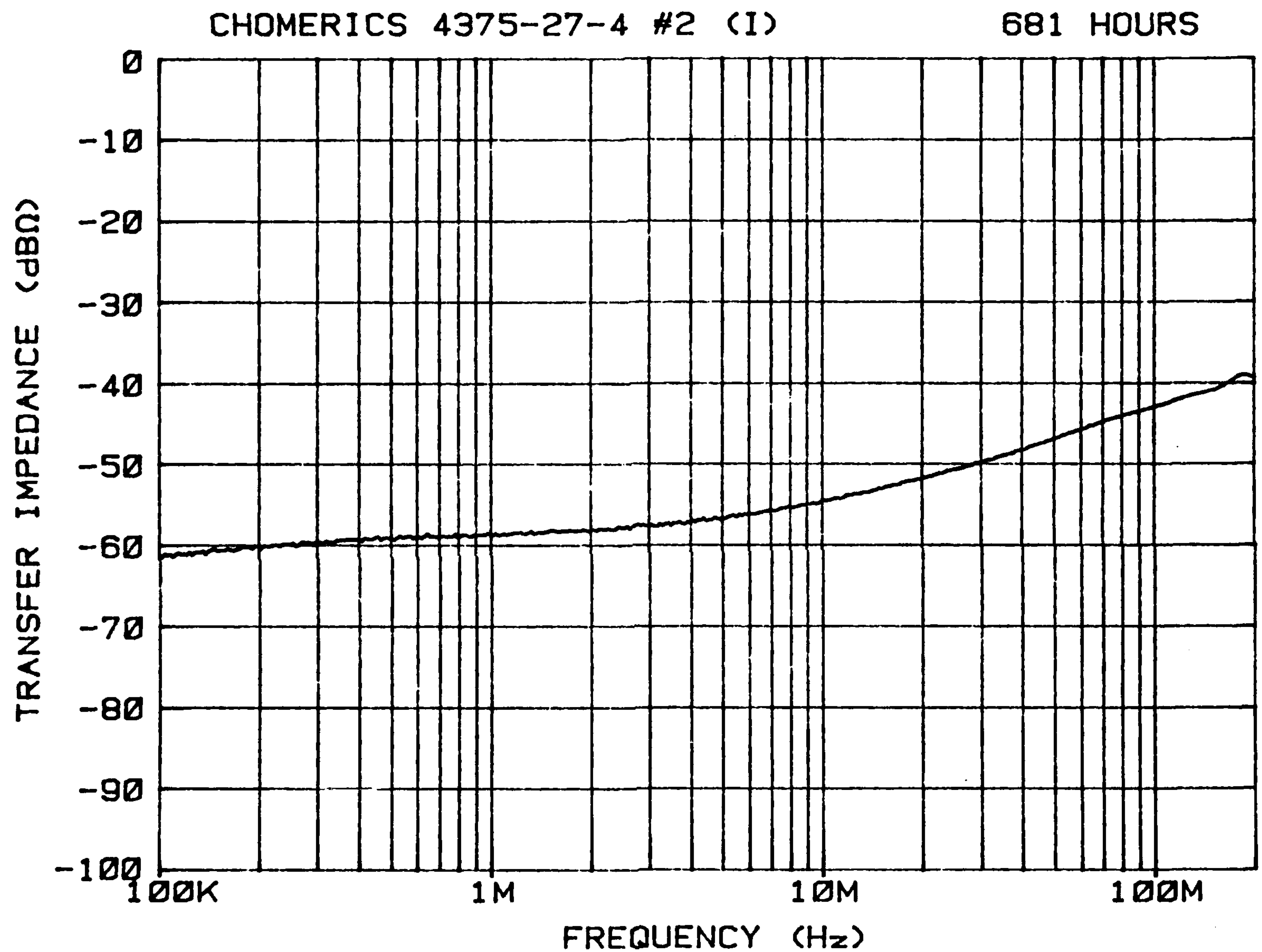
Test Sample B3, 304 Hrs.



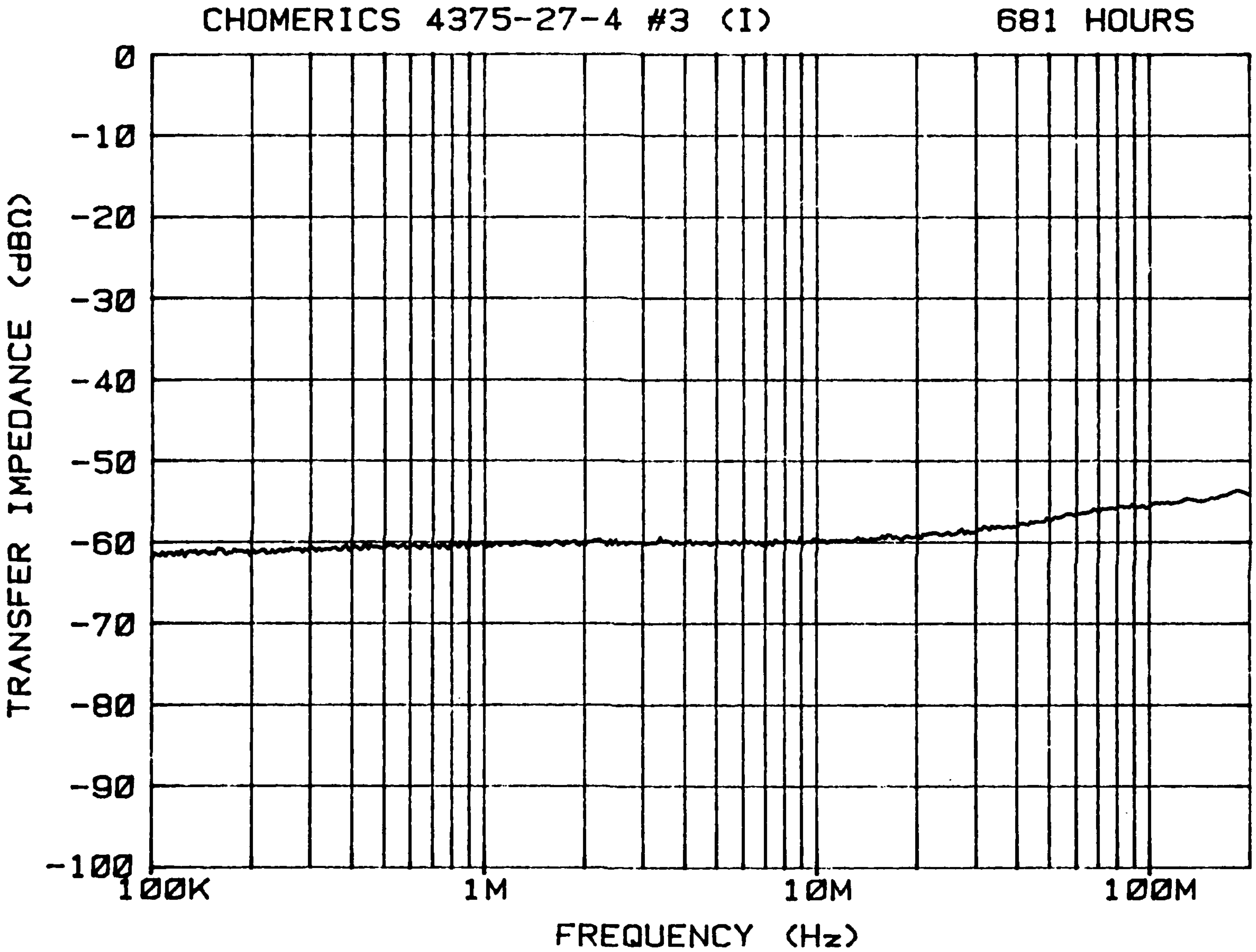
Test Sample A1, 681 Hrs.



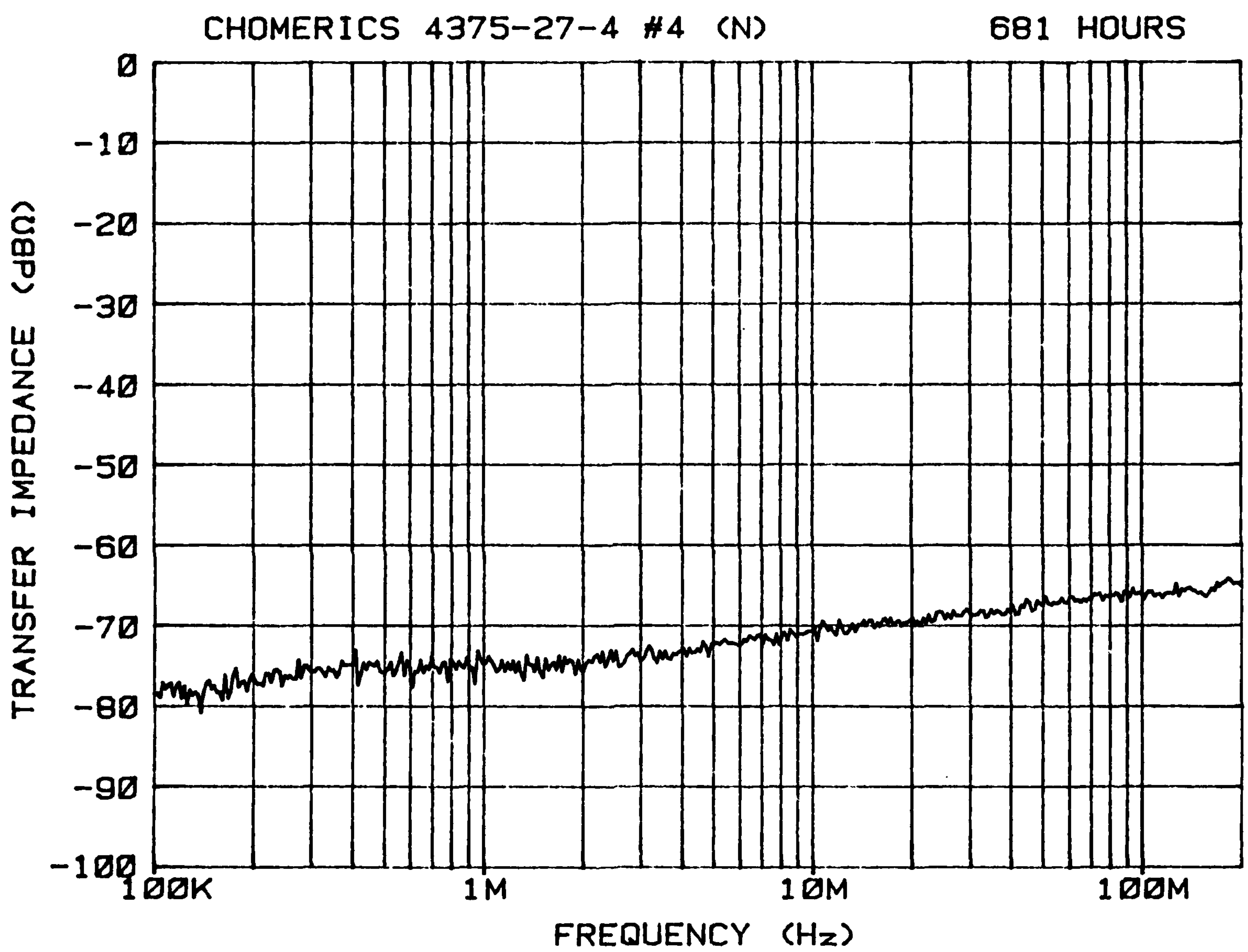
Test Sample A2, 681 Hrs.



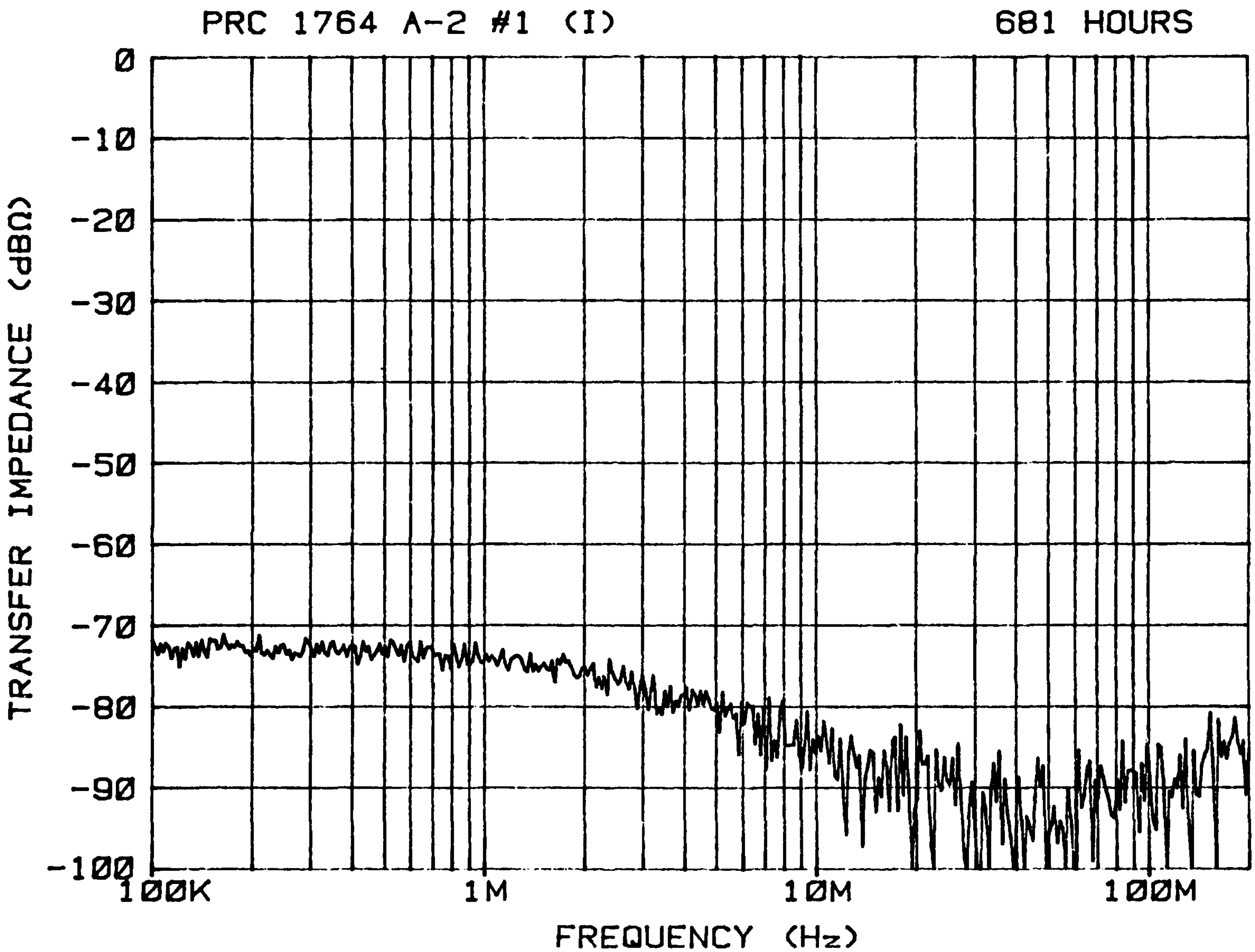
Test Sample A3, 681 Hrs.



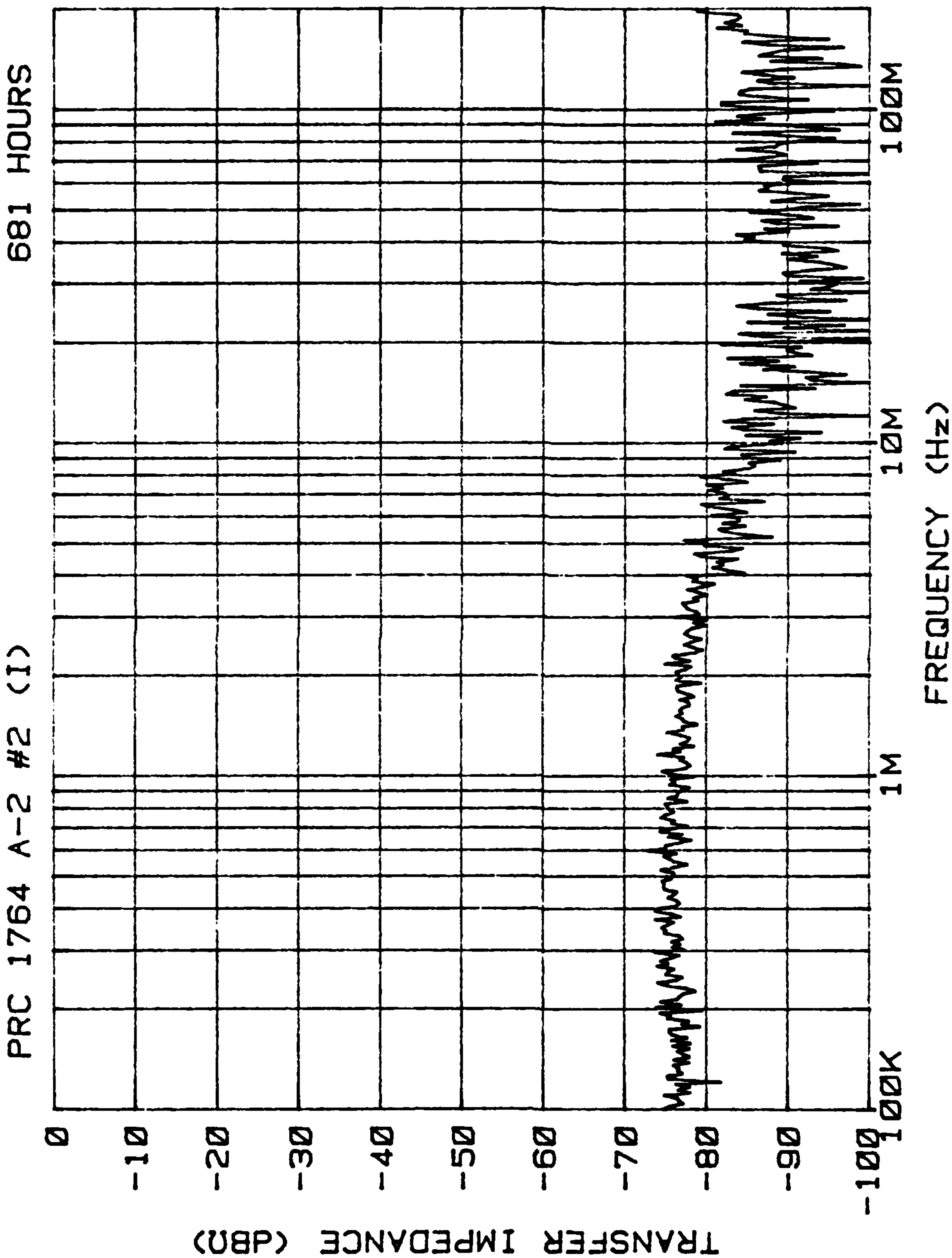
Test Sample A4, 681 Hrs.

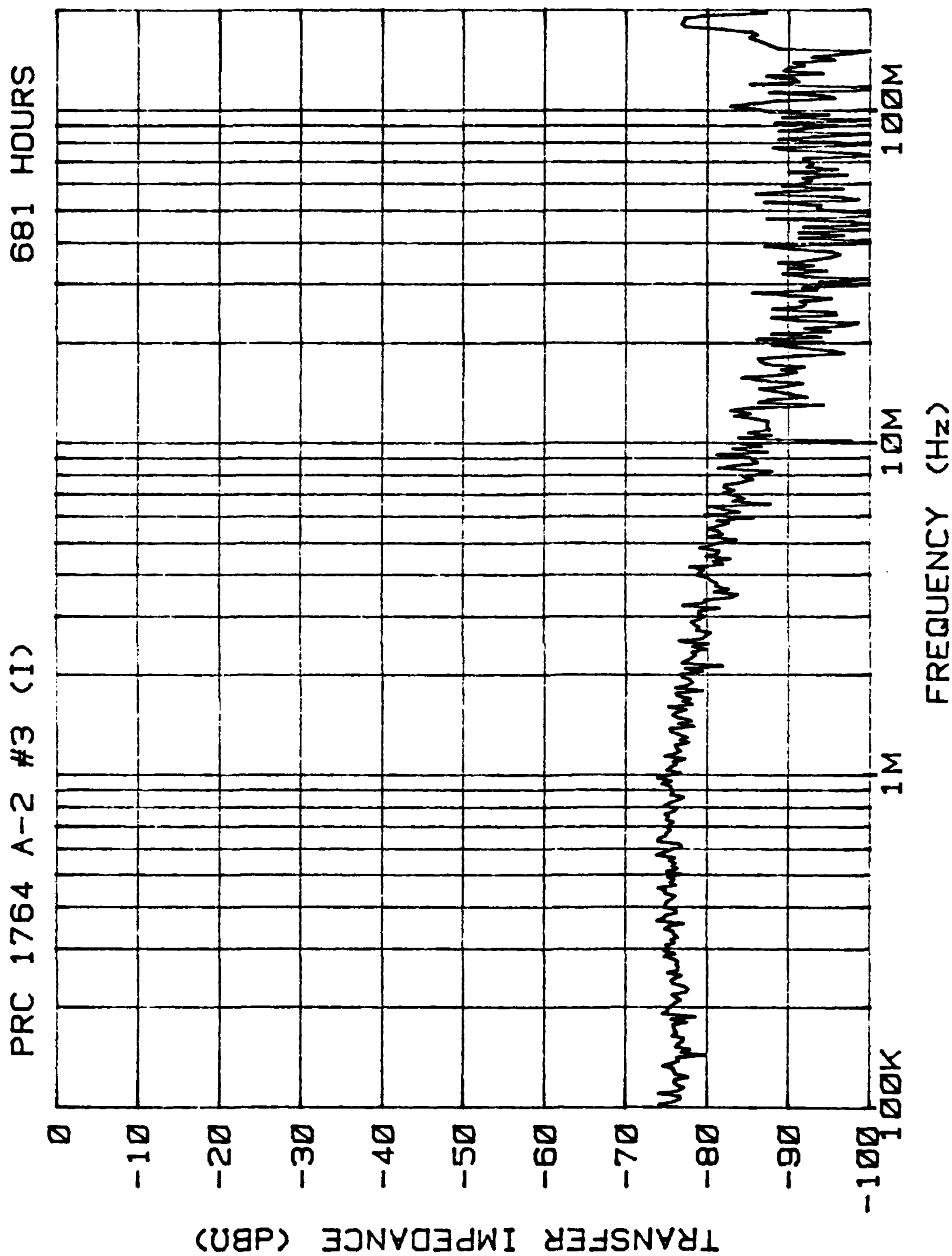


Test Sample Cl, 681 Hrs.



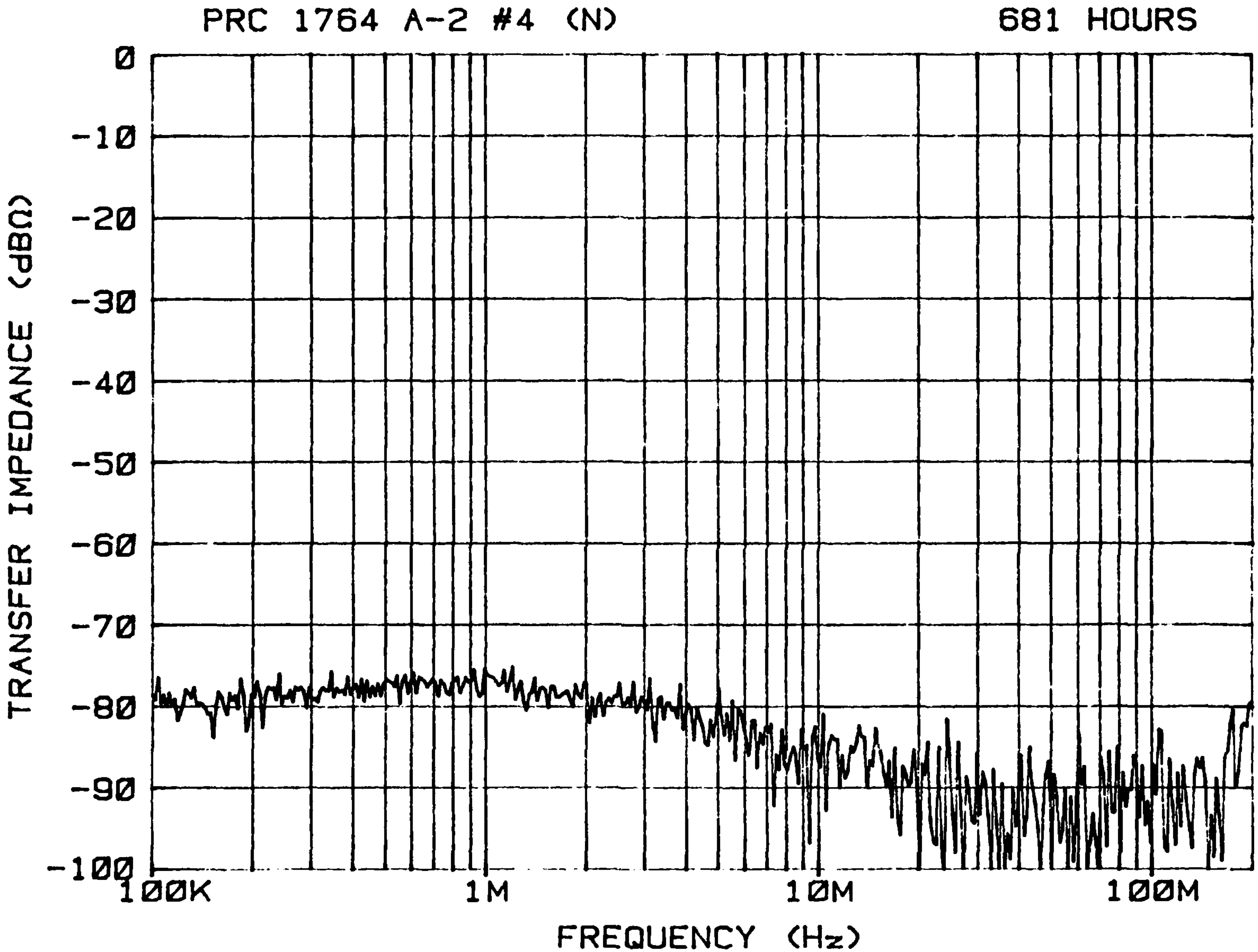
Test Sample C2, 681 Hrs.



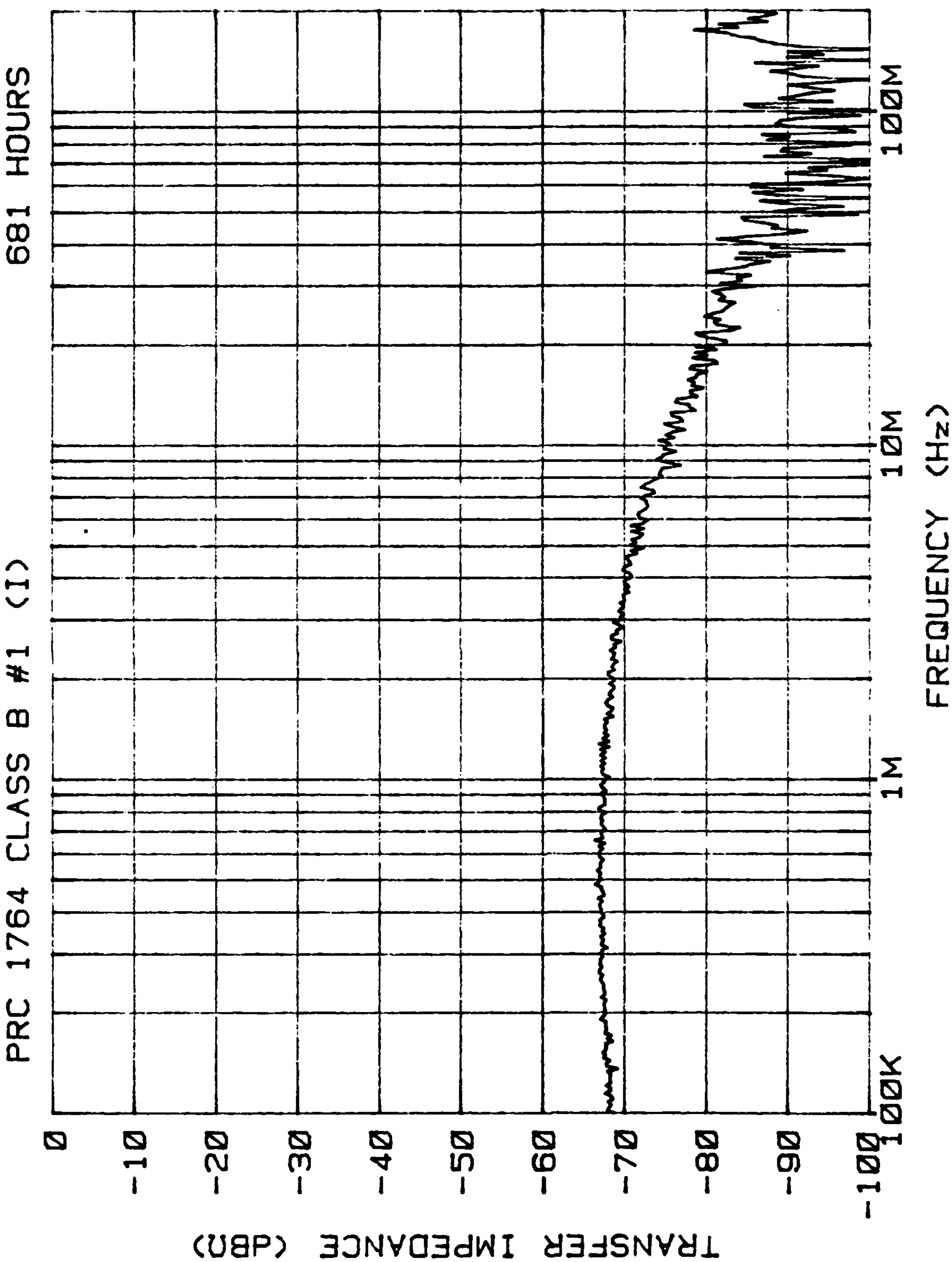


Test Sample C3, 681 Hrs.

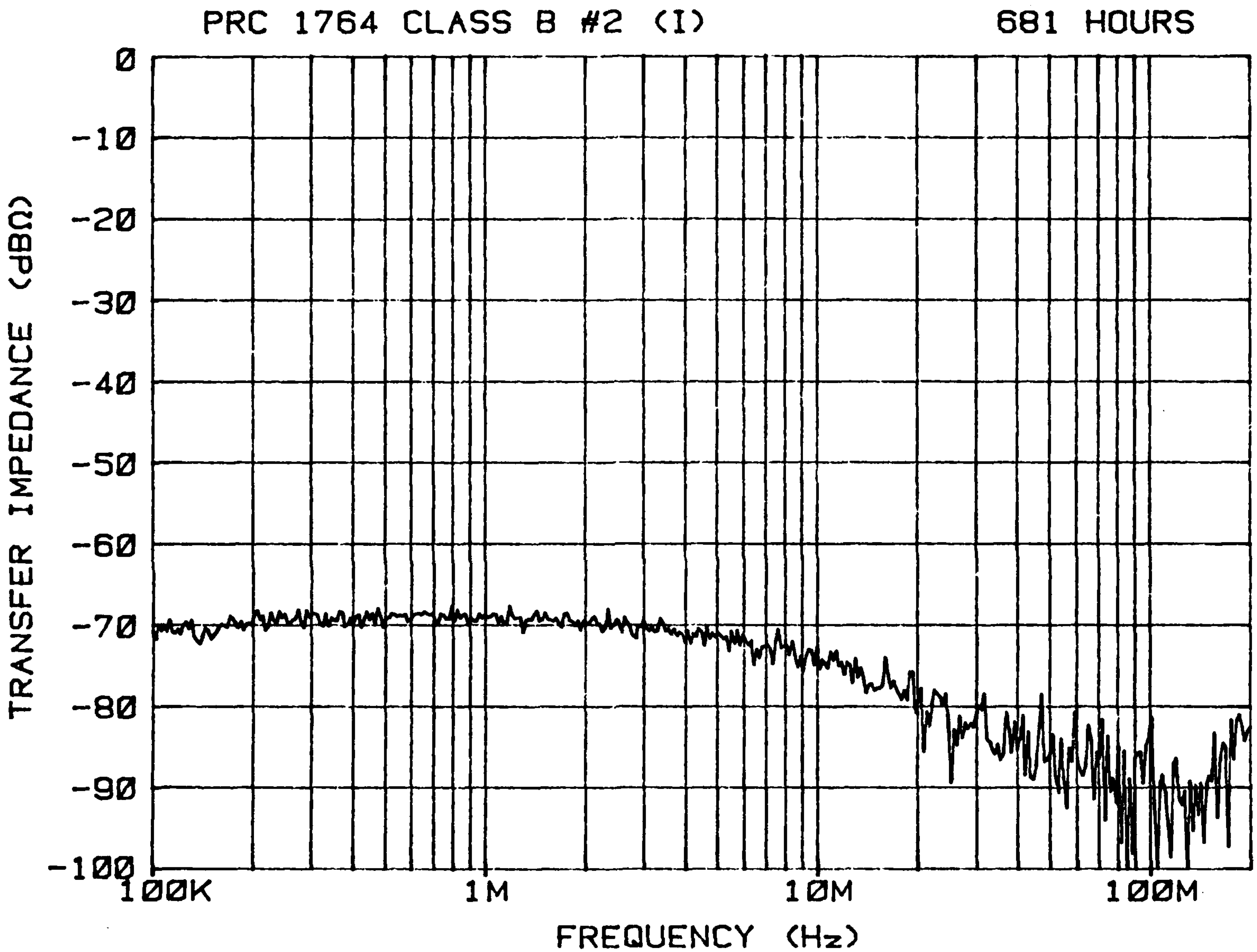
Test Sample C4, 681 Hrs.



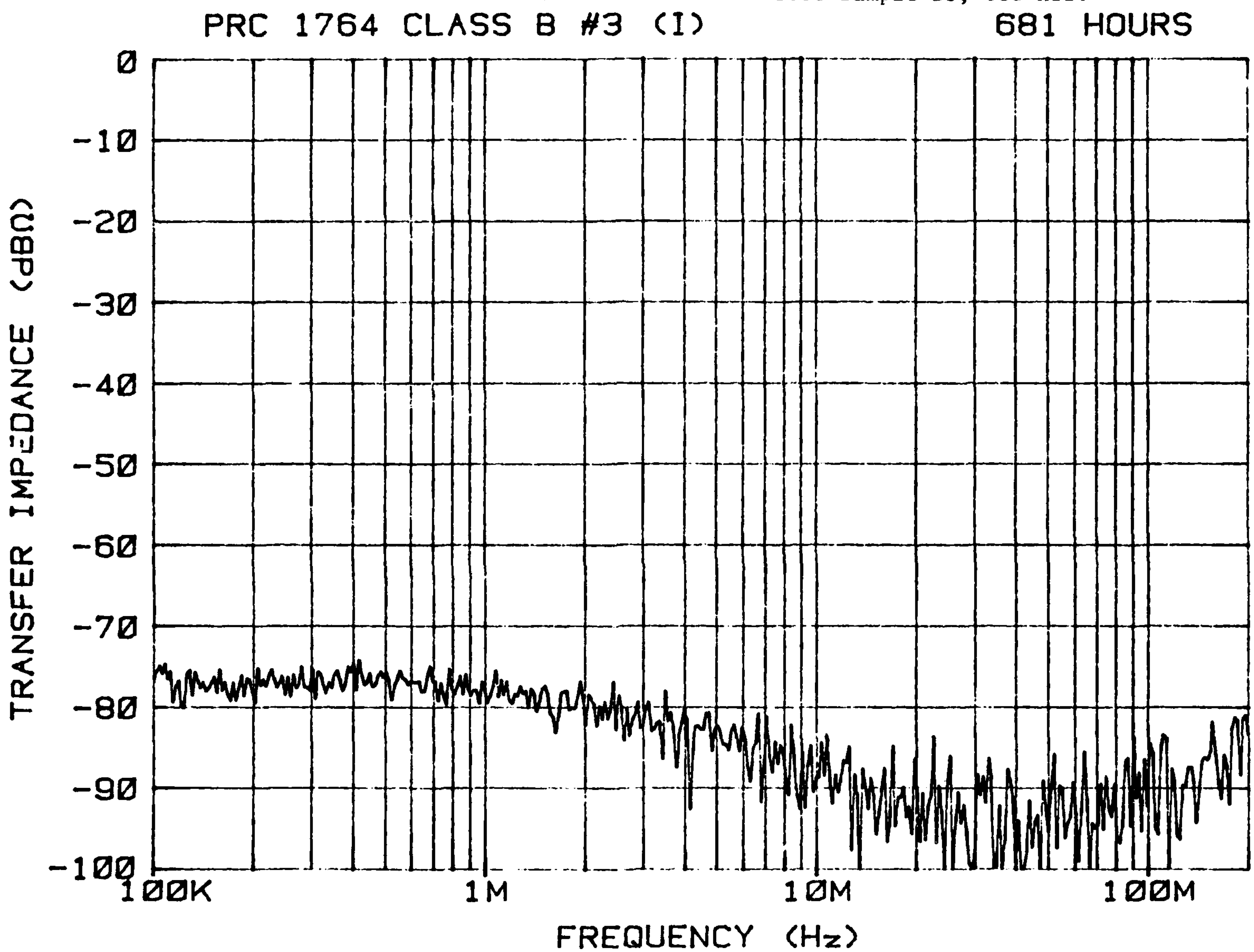
Test Sample D1, 681 Hrs.



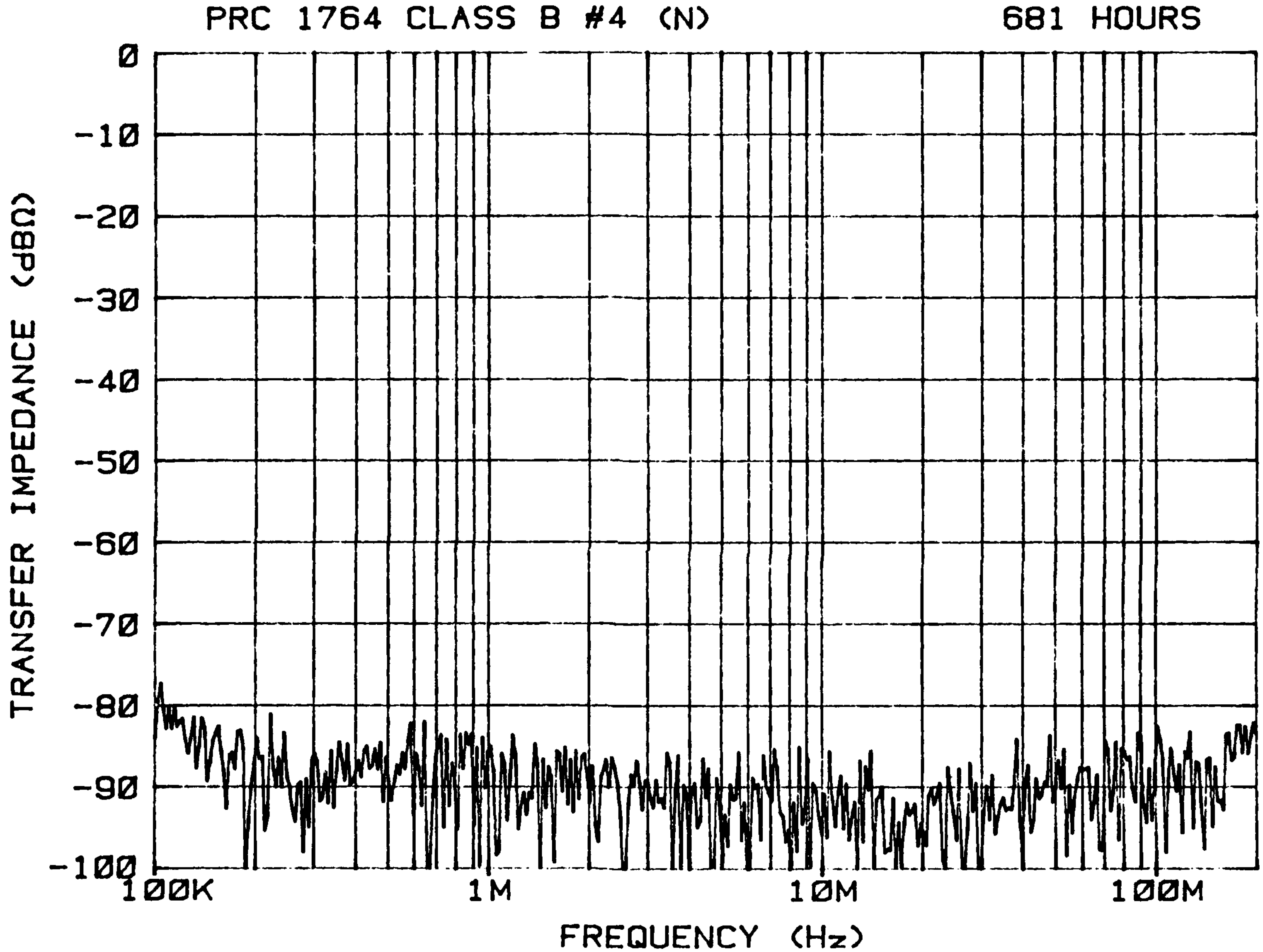
Test Sample D2, 681 Hrs.



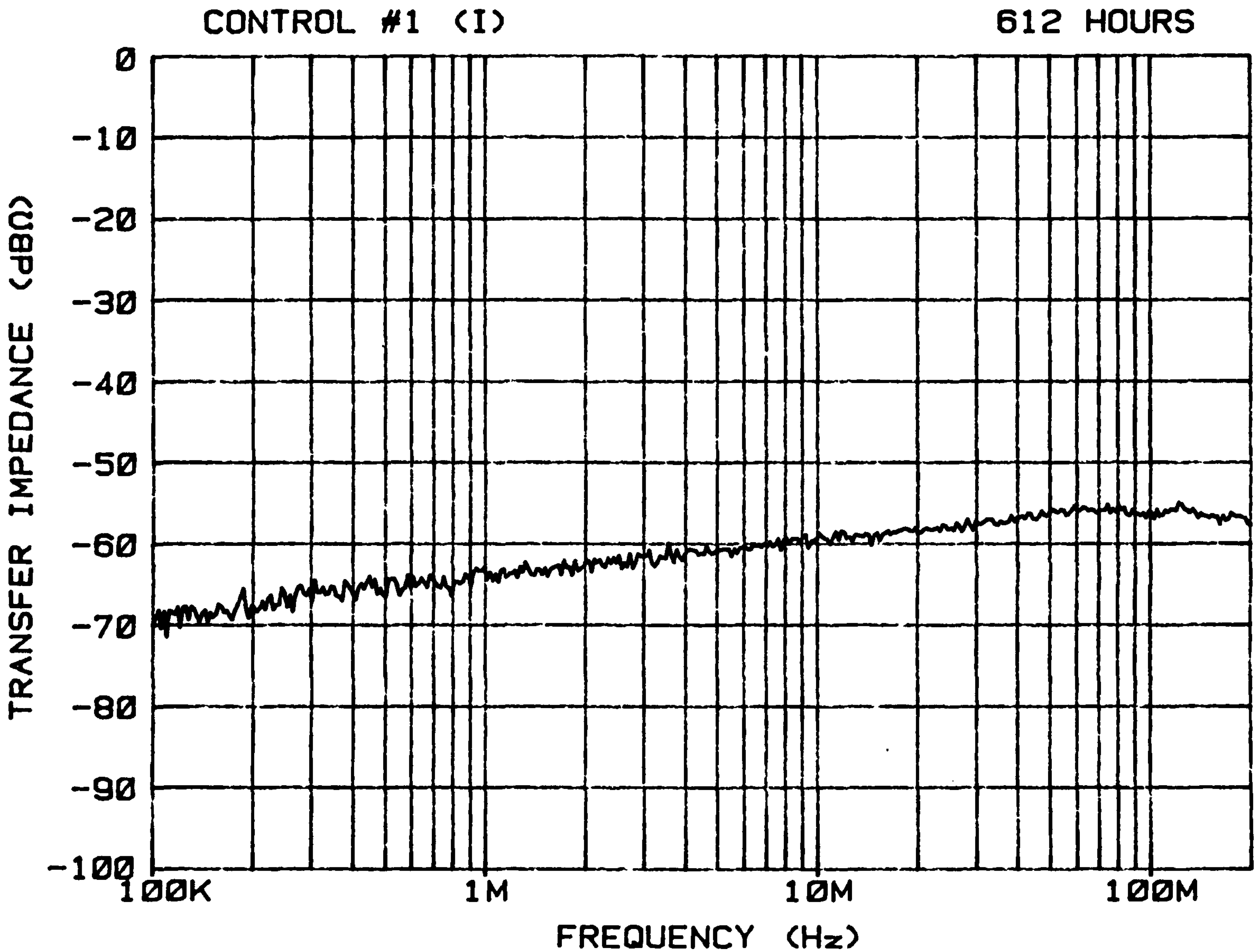
Test Sample D3, 681 Hrs.



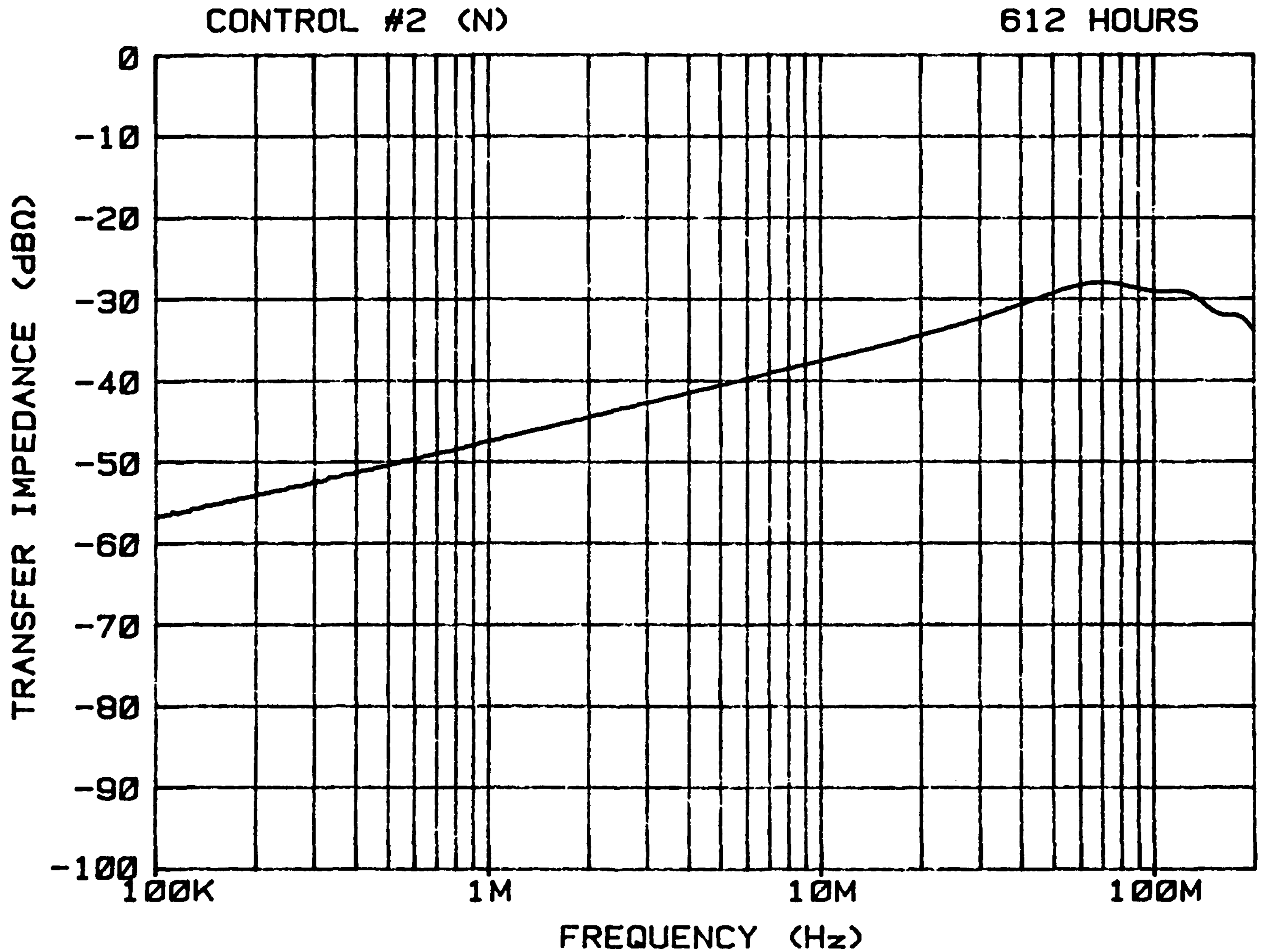
Test Sample B4, 681 Hrs.



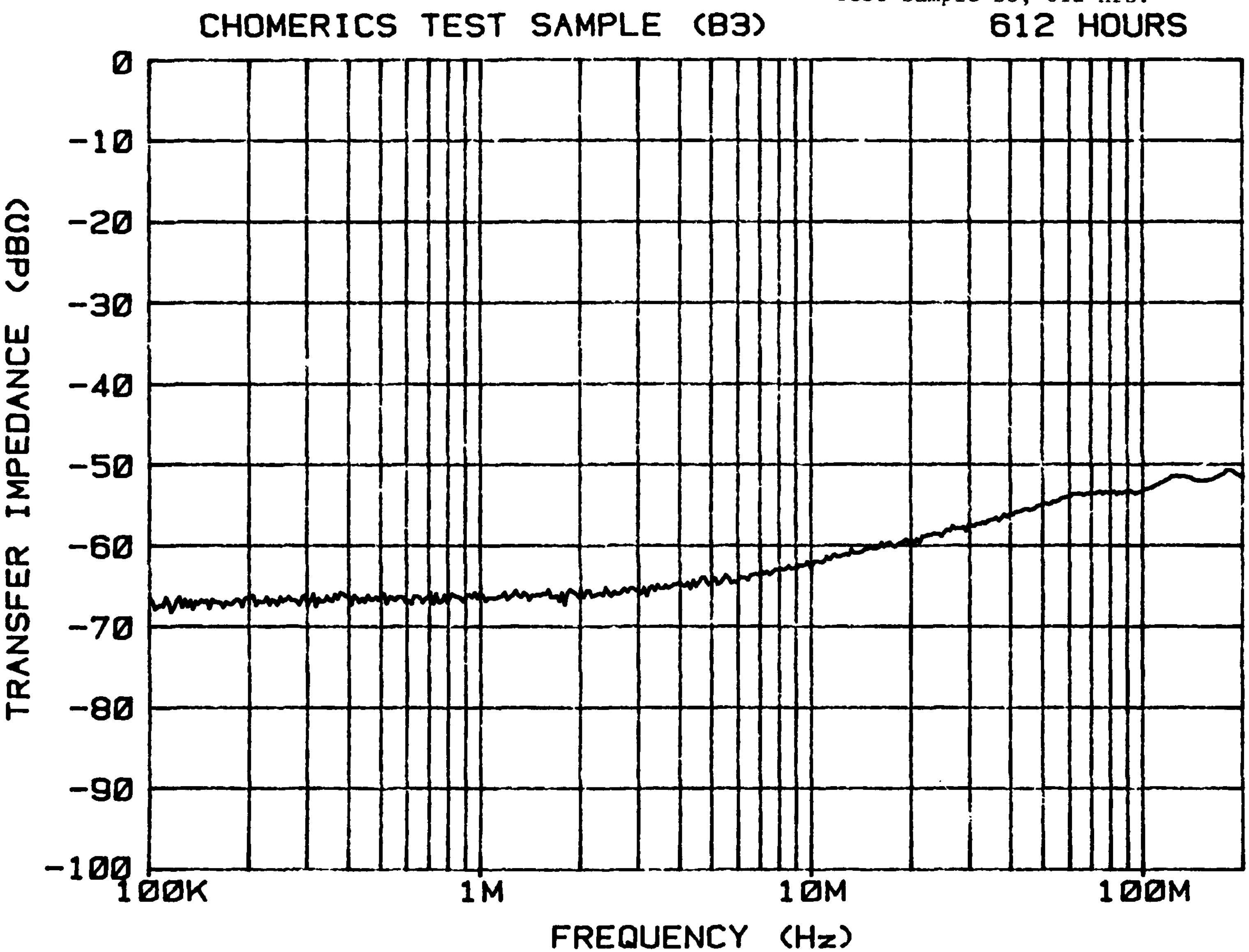
Test Sample B1, 612 Hrs.



Test Sample B2, 612 Hrs.

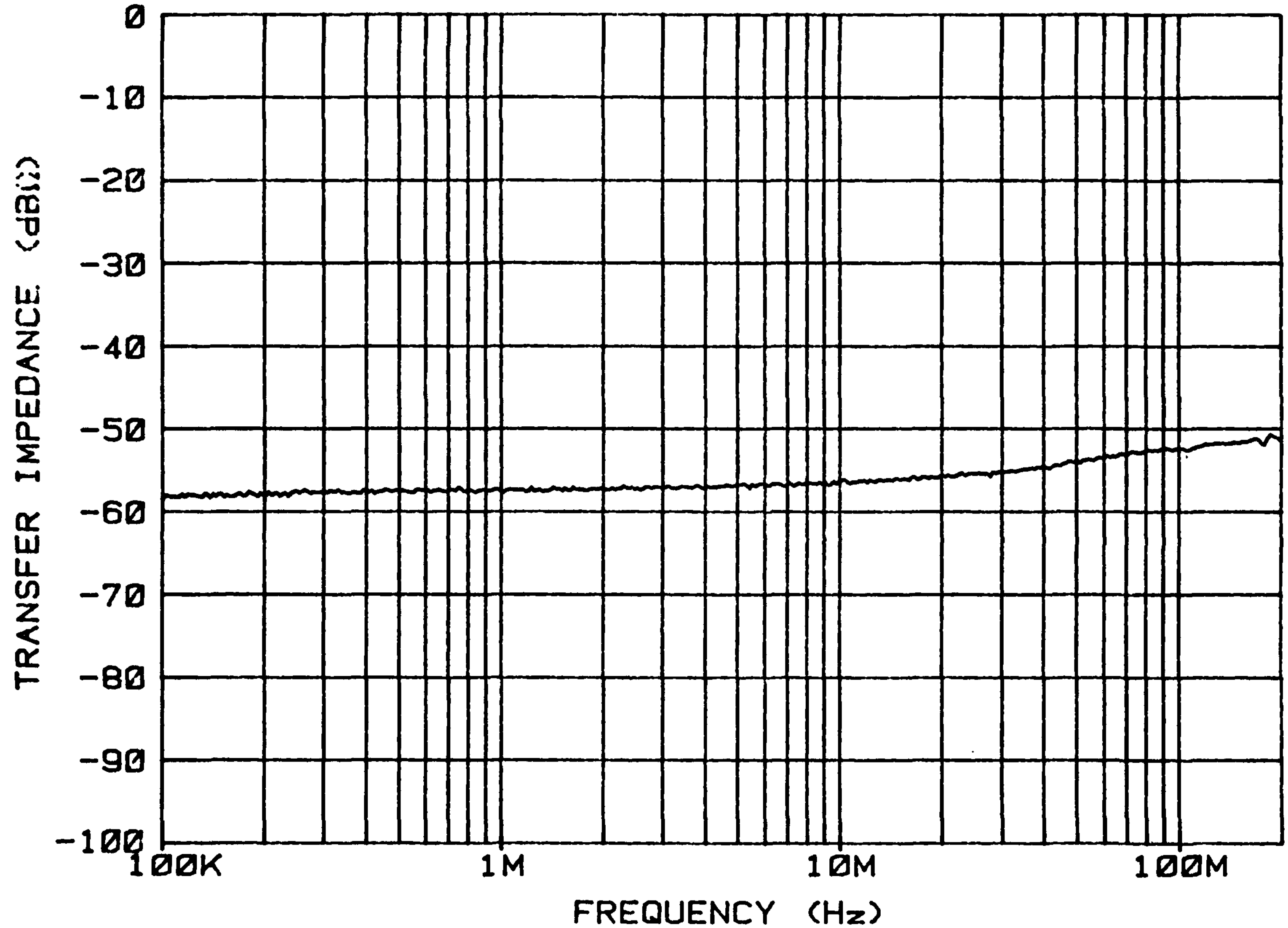


Test Sample B3, 612 Hrs.

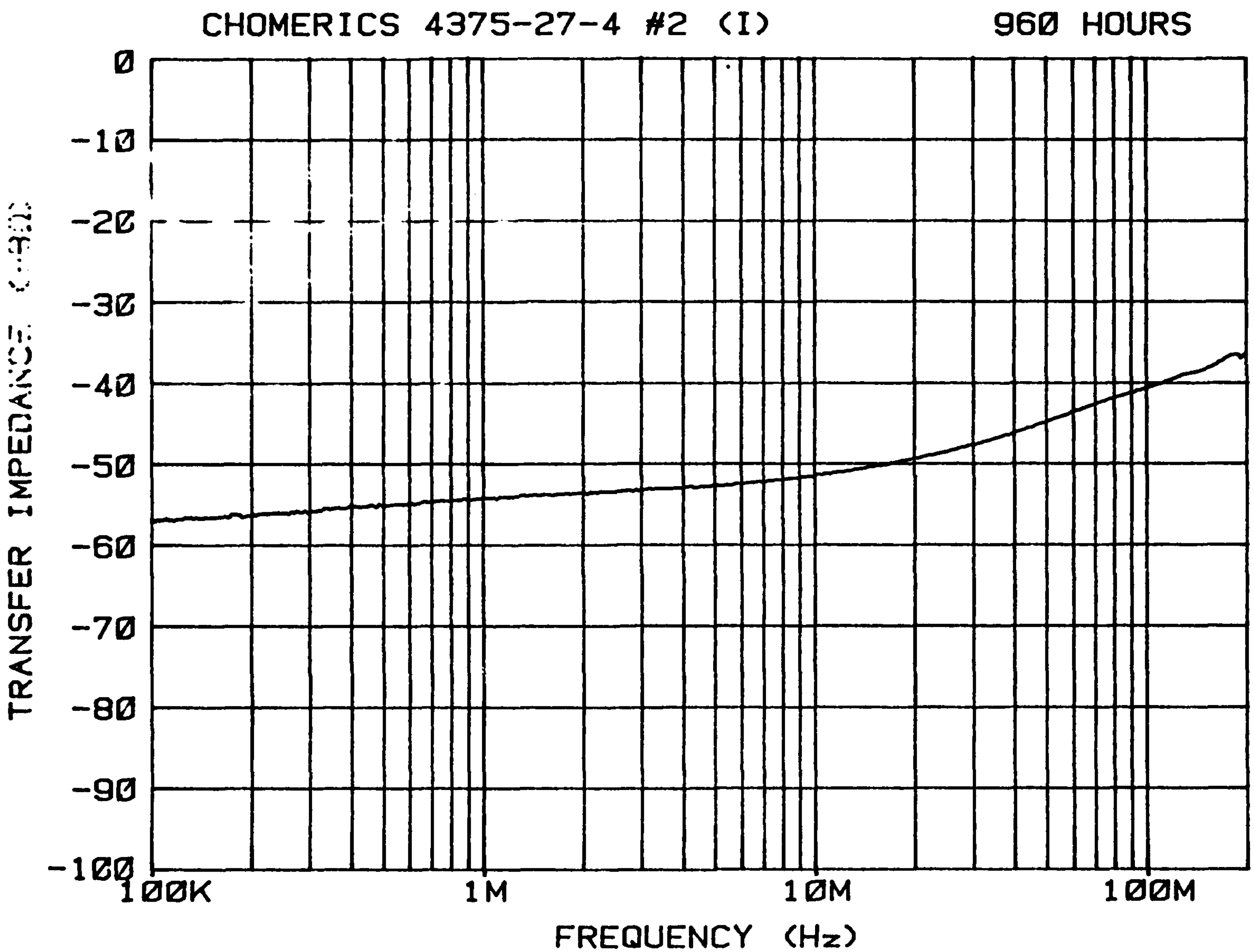


Test Sample Al, 960 Hrs.

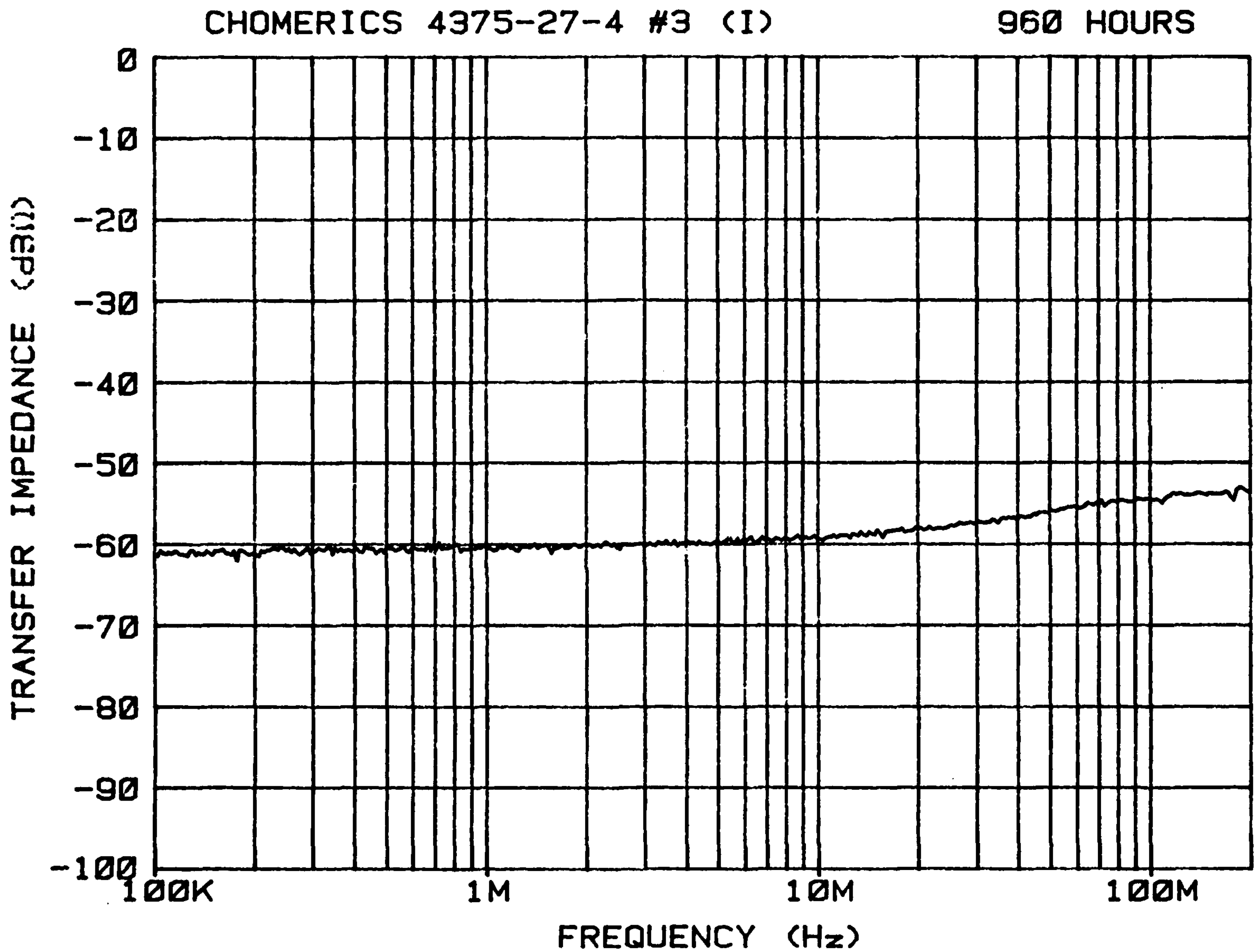
CHOMERICS 4375-27-4 #1 (I) 960 HOURS



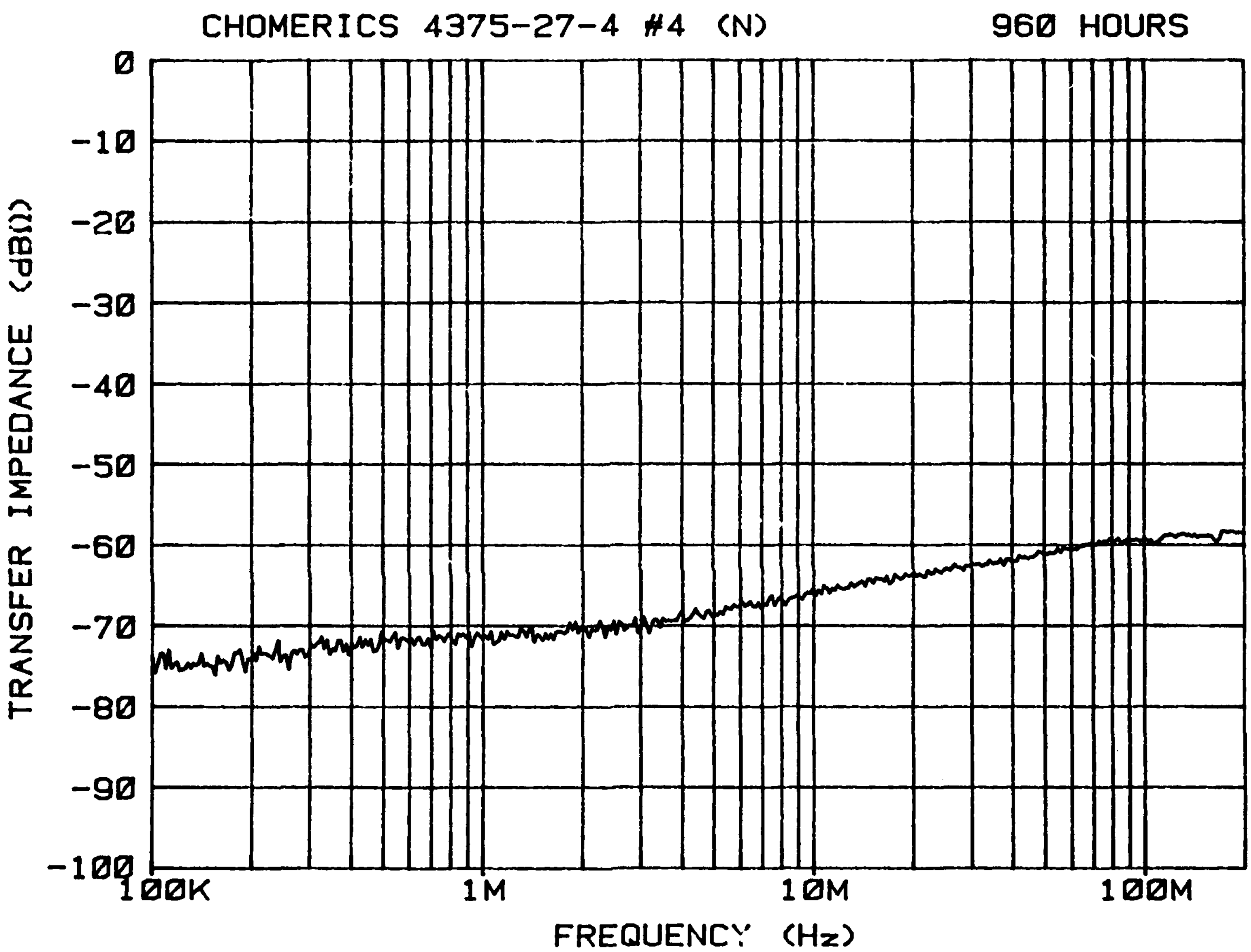
Test Sample A2, 960 Hrs.



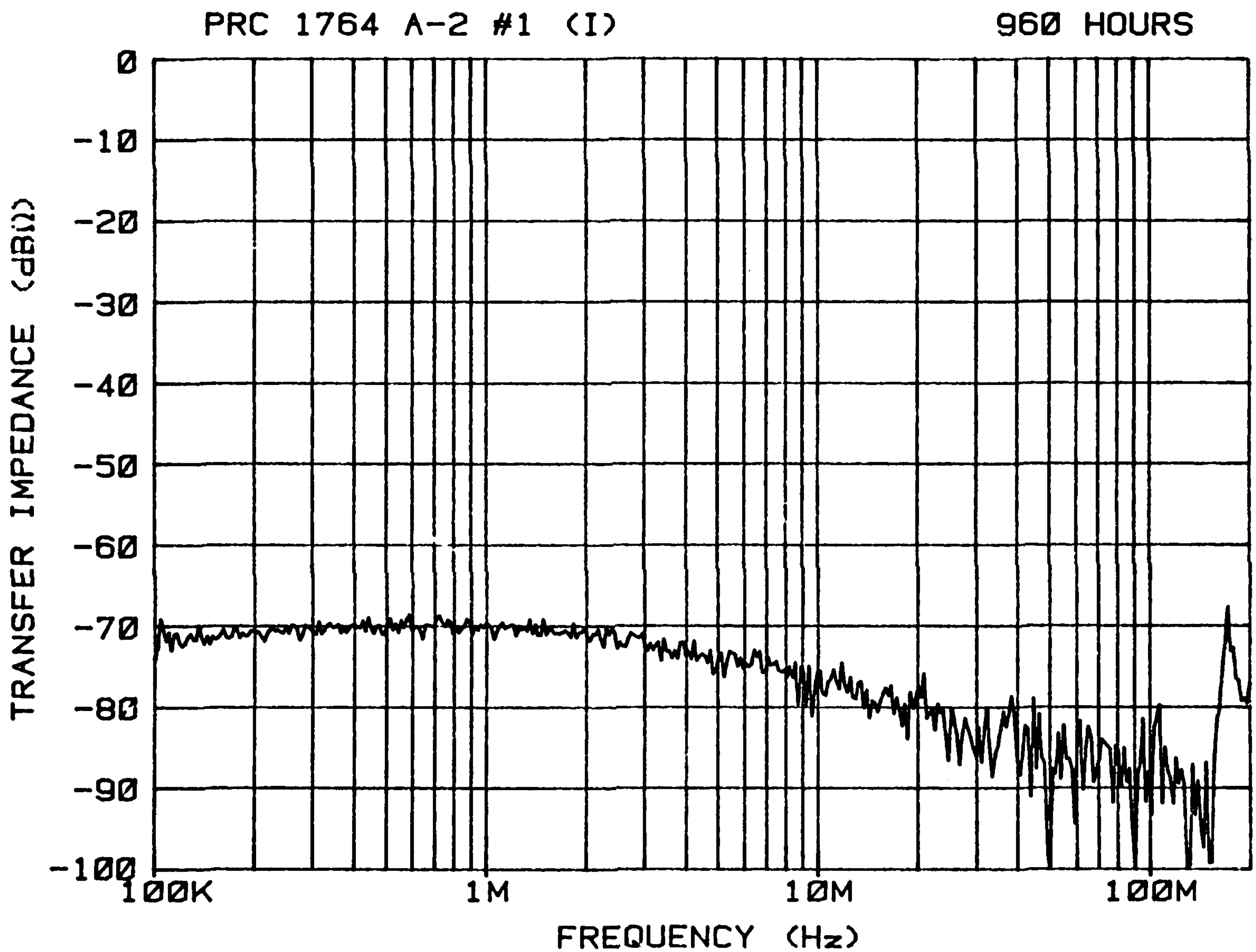
Test Sample A4, 960 Hrs.



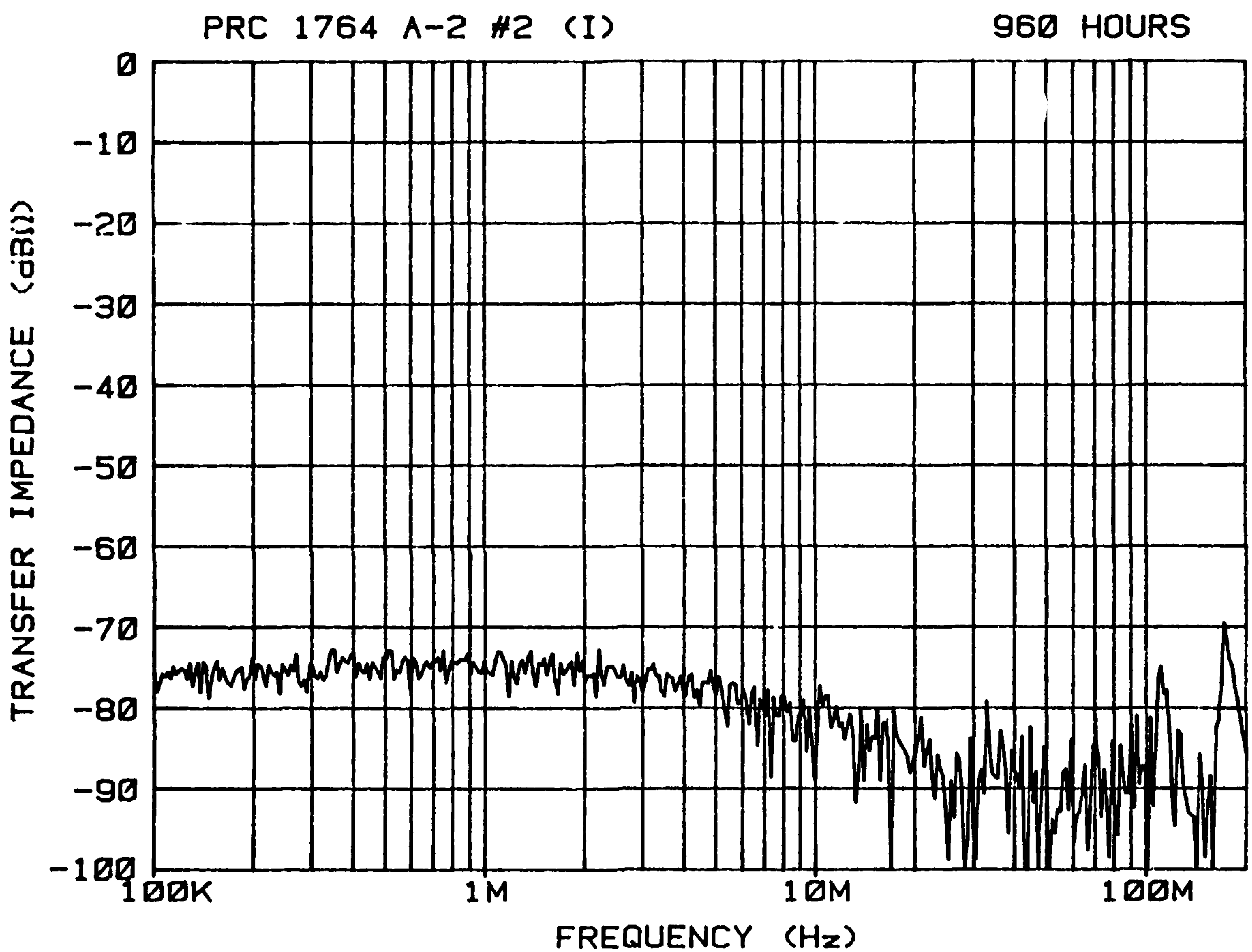
Test Sample A4, 960 Hrs.



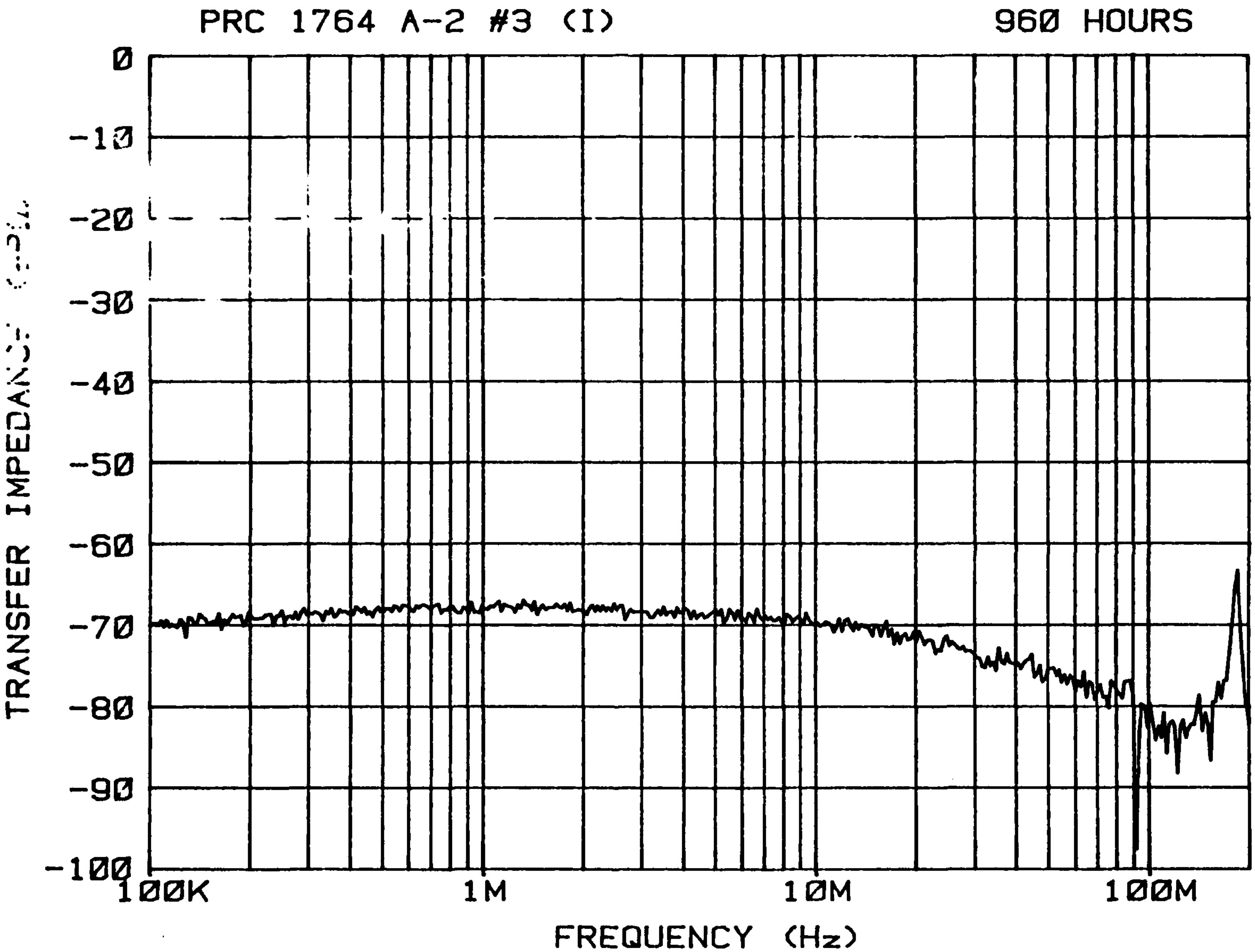
Test Sample C1, 960 Hrs.



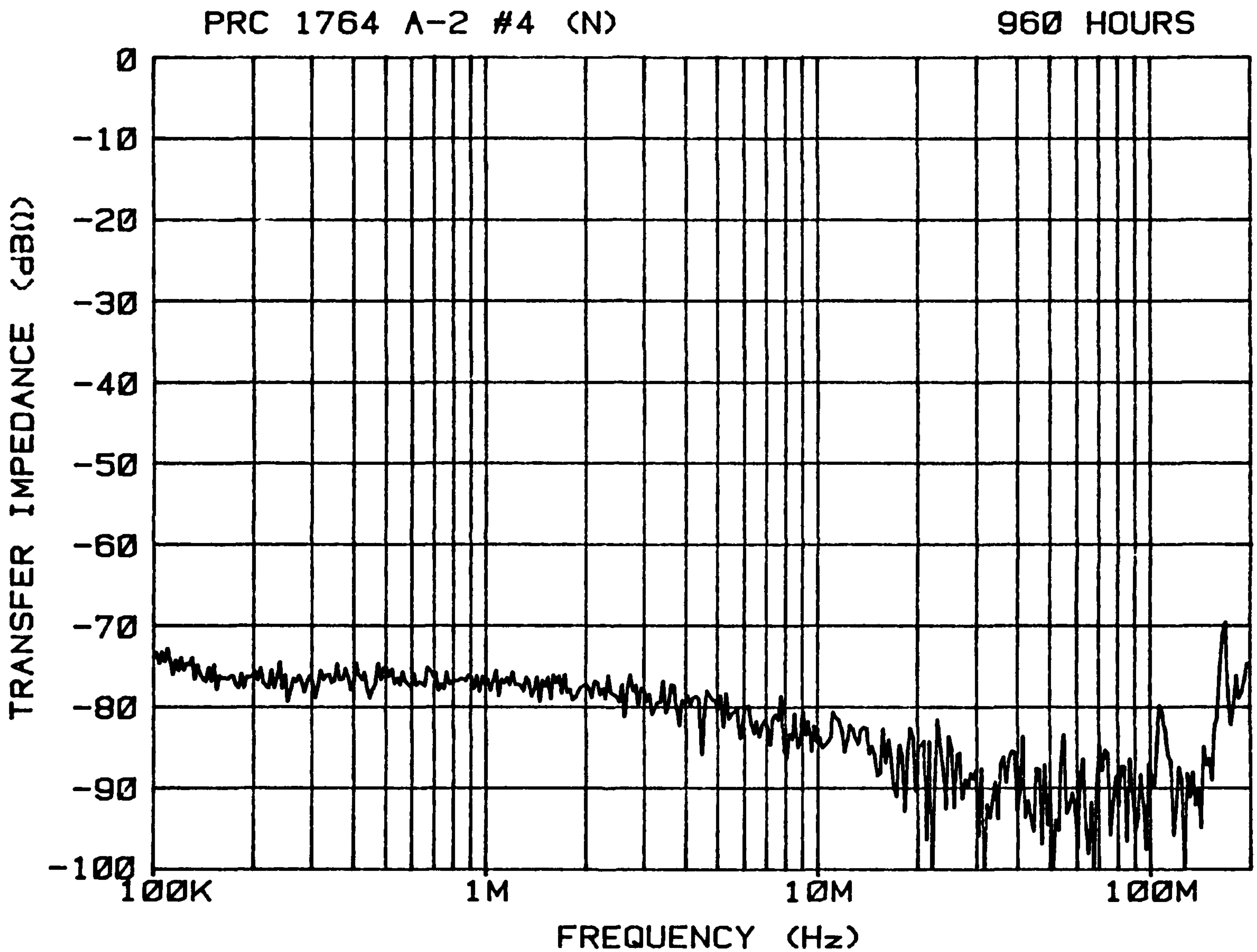
Test Sample C2, 960 Hrs.



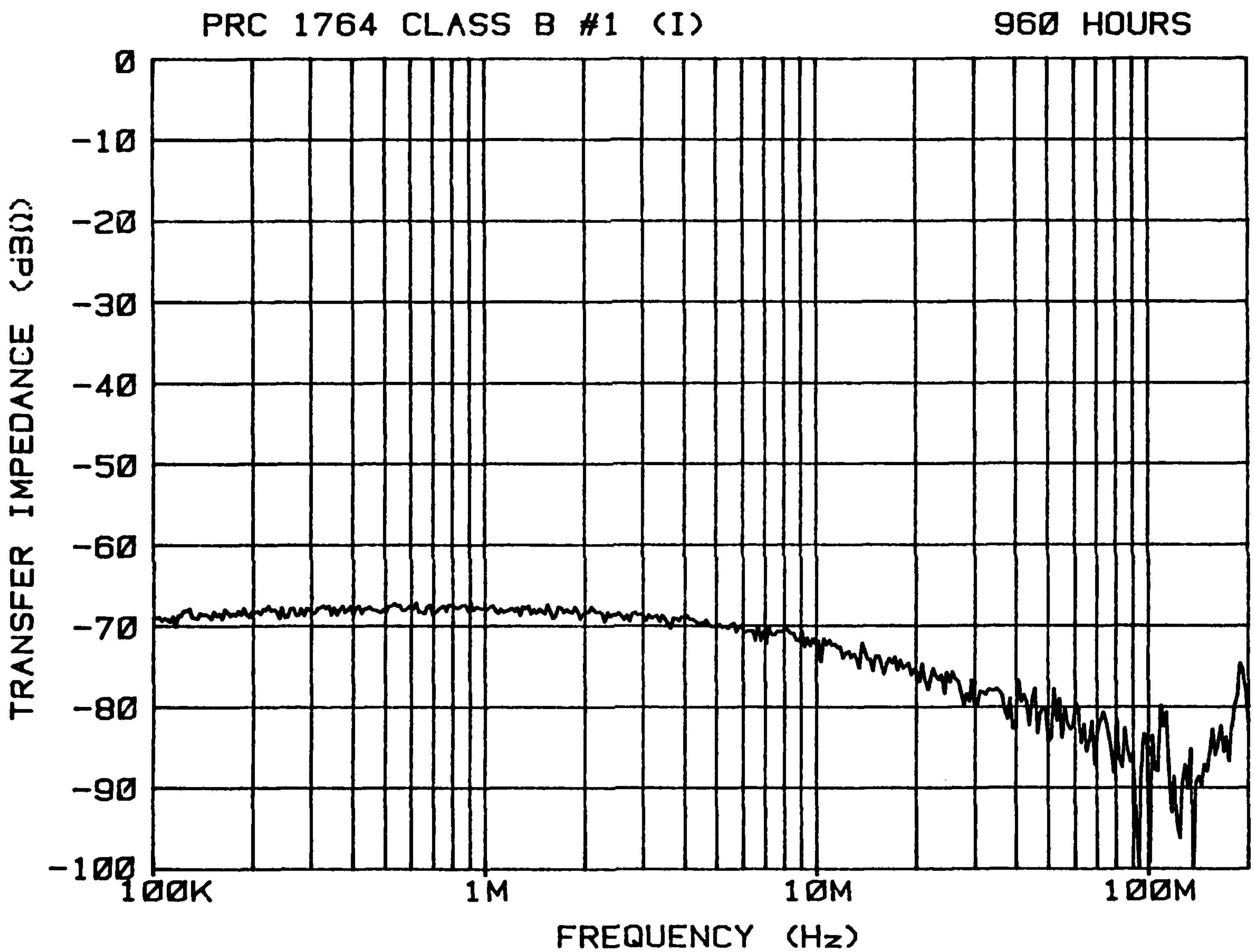
Test Sample C3, 960 Hrs.



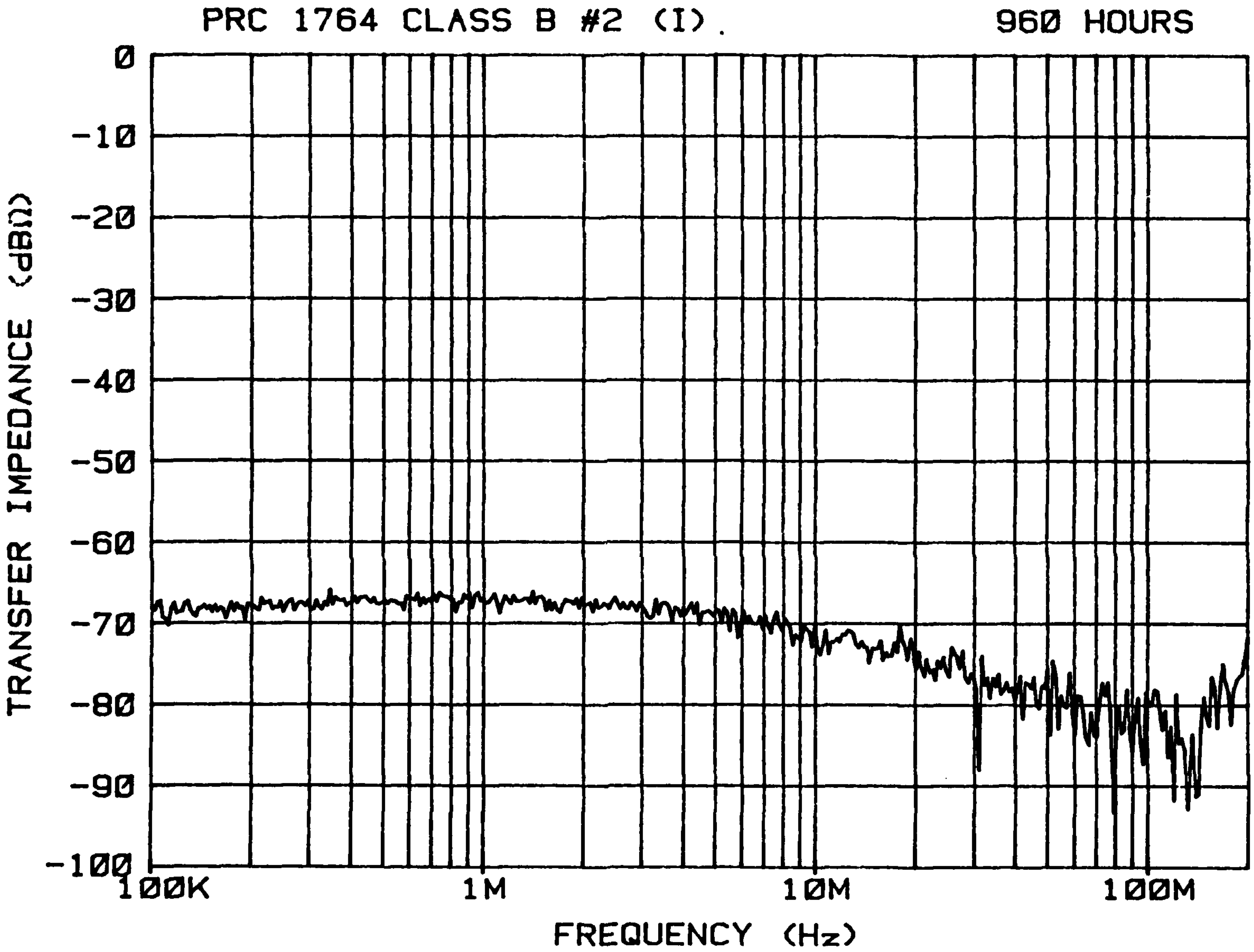
Test Sample C4, 960 Hrs.



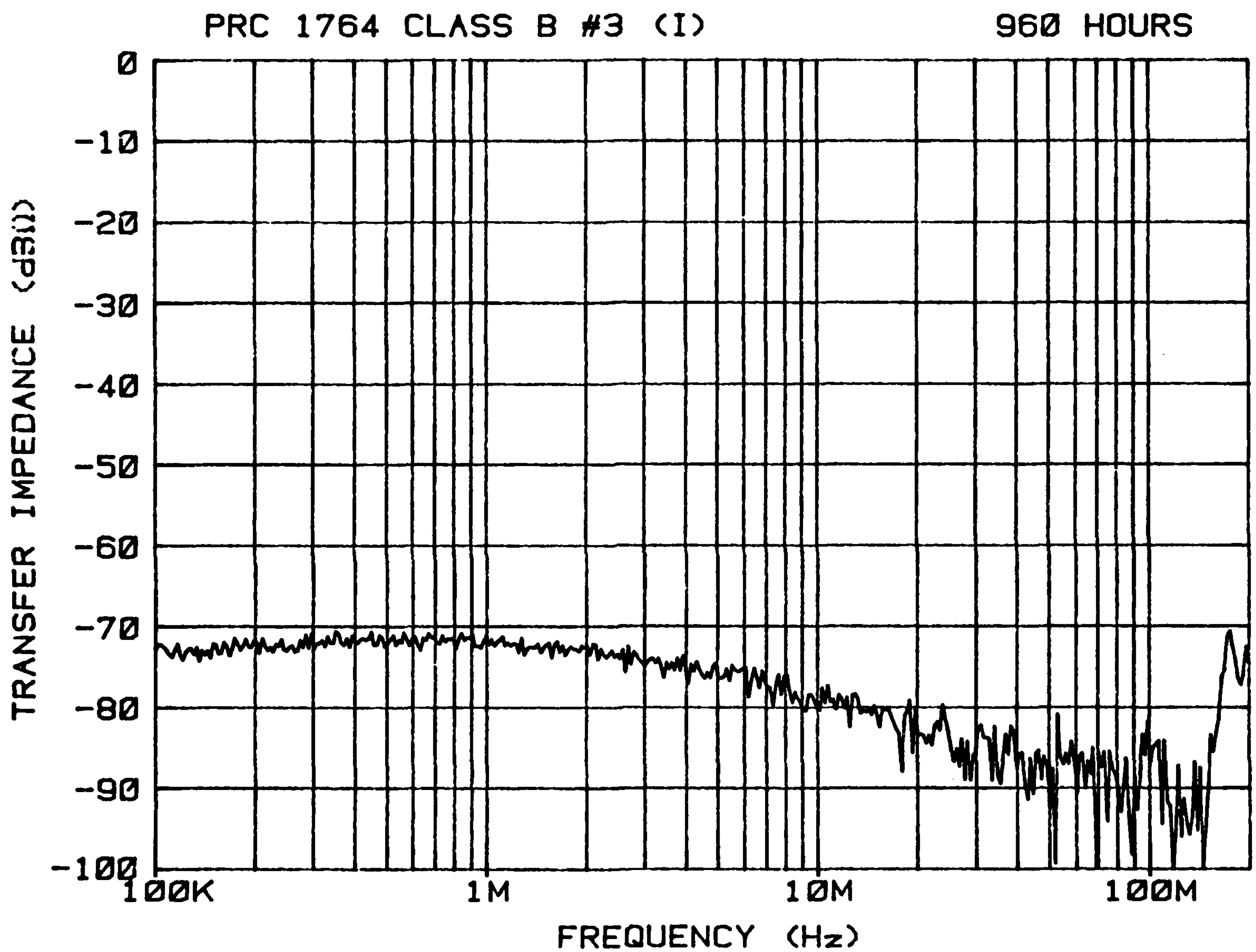
Test Sample D1, 960 Hrs.



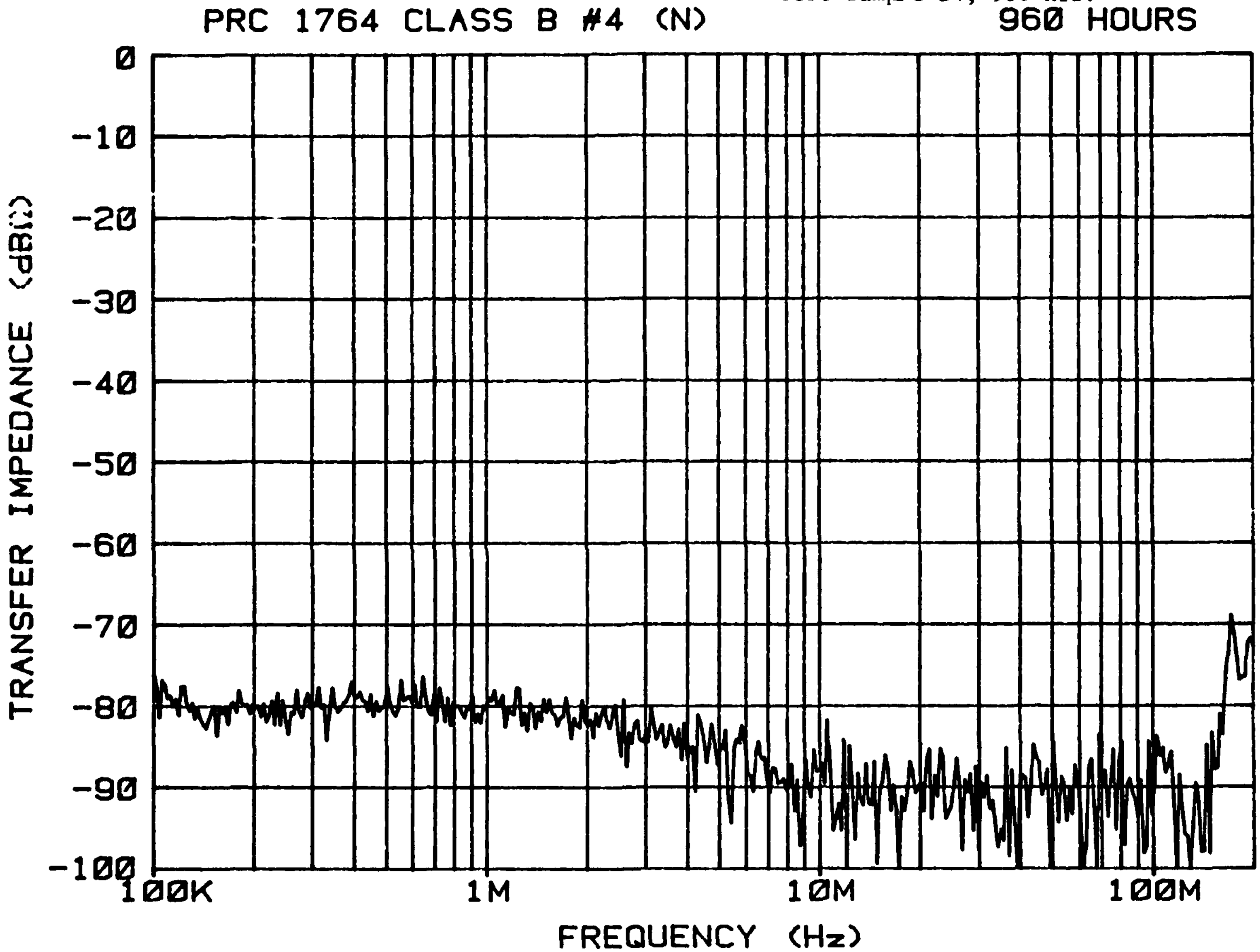
Test Sample D2, 960 Hrs.



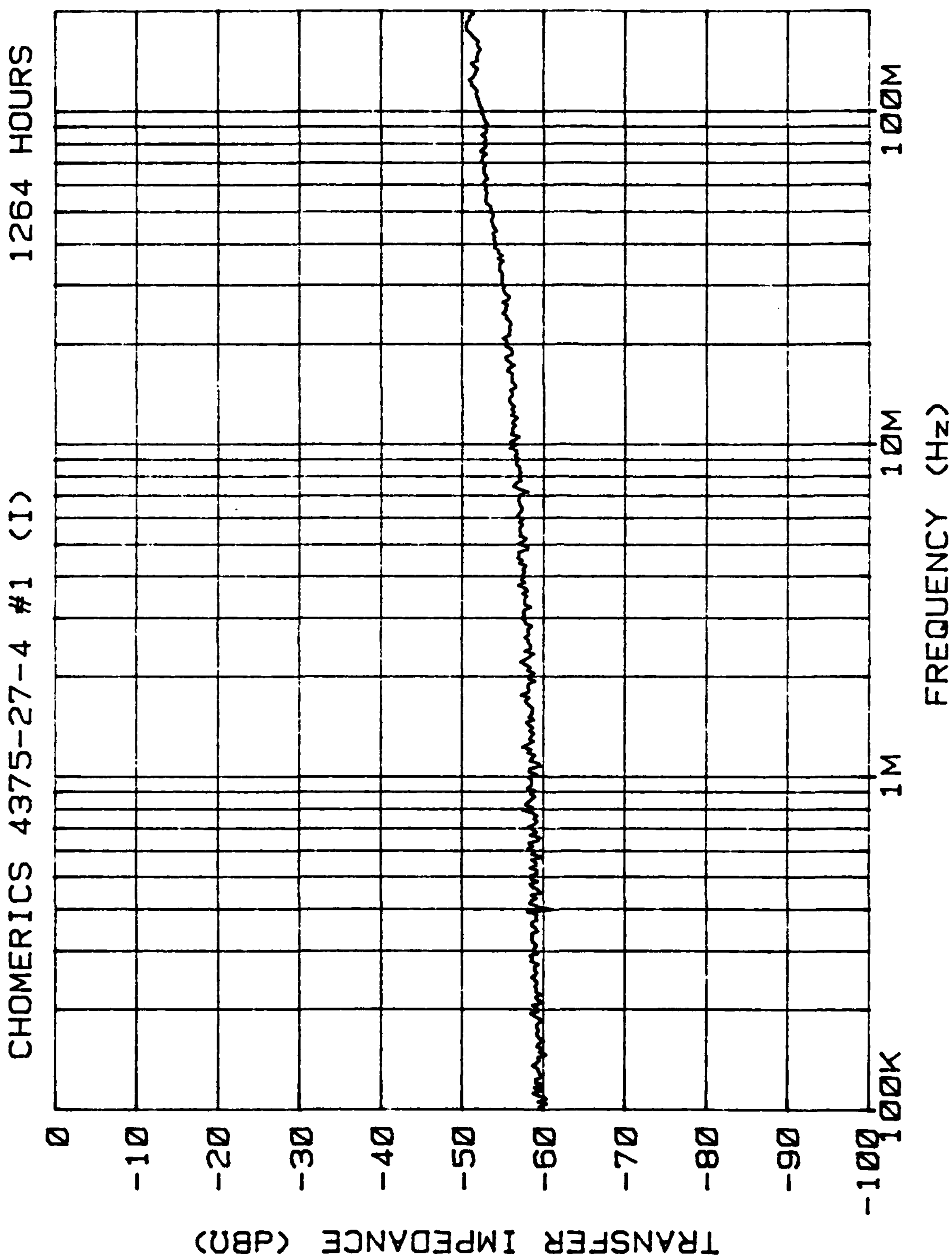
Test Sample D3, 960 Hrs.



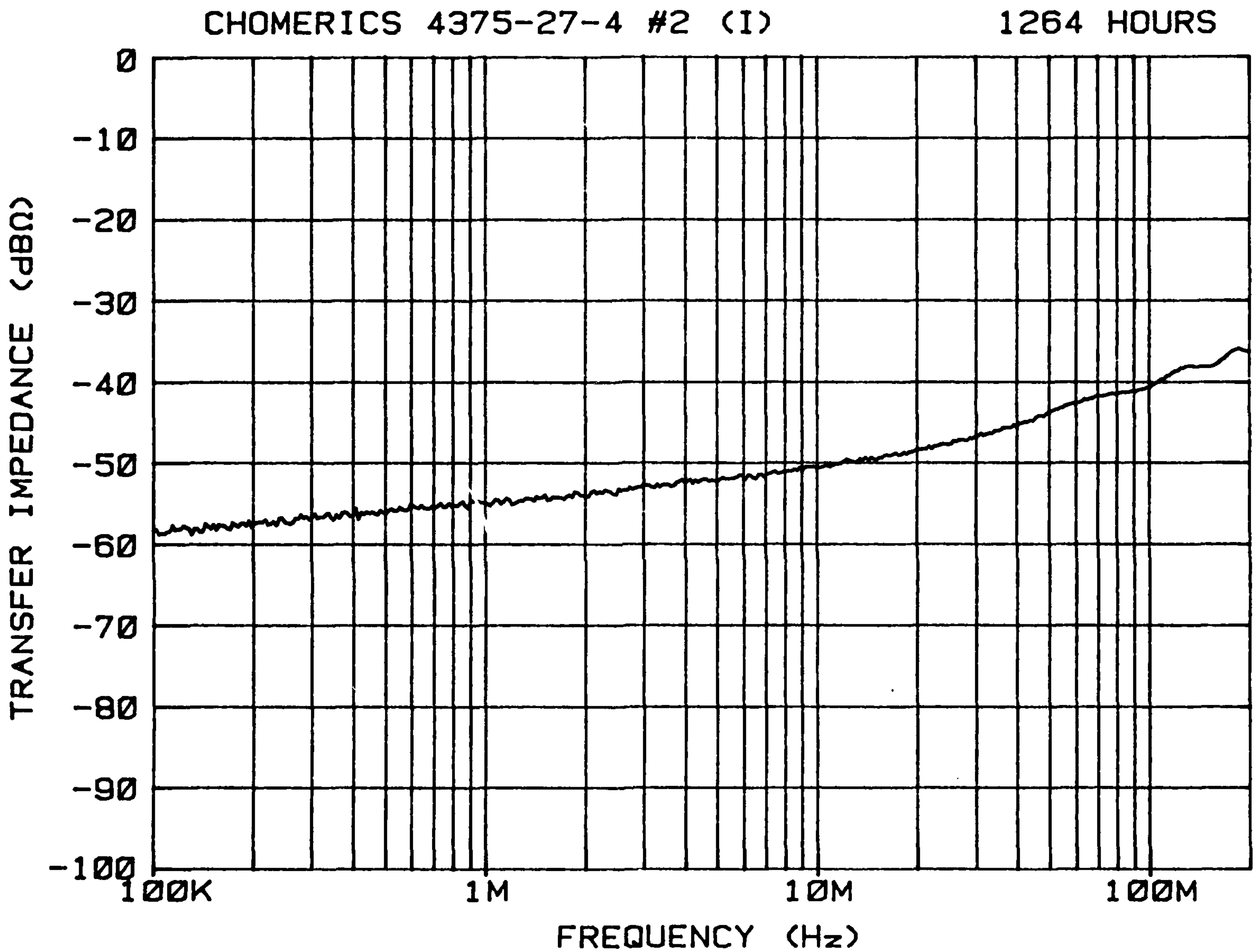
Test Sample D4, 960 Hrs.



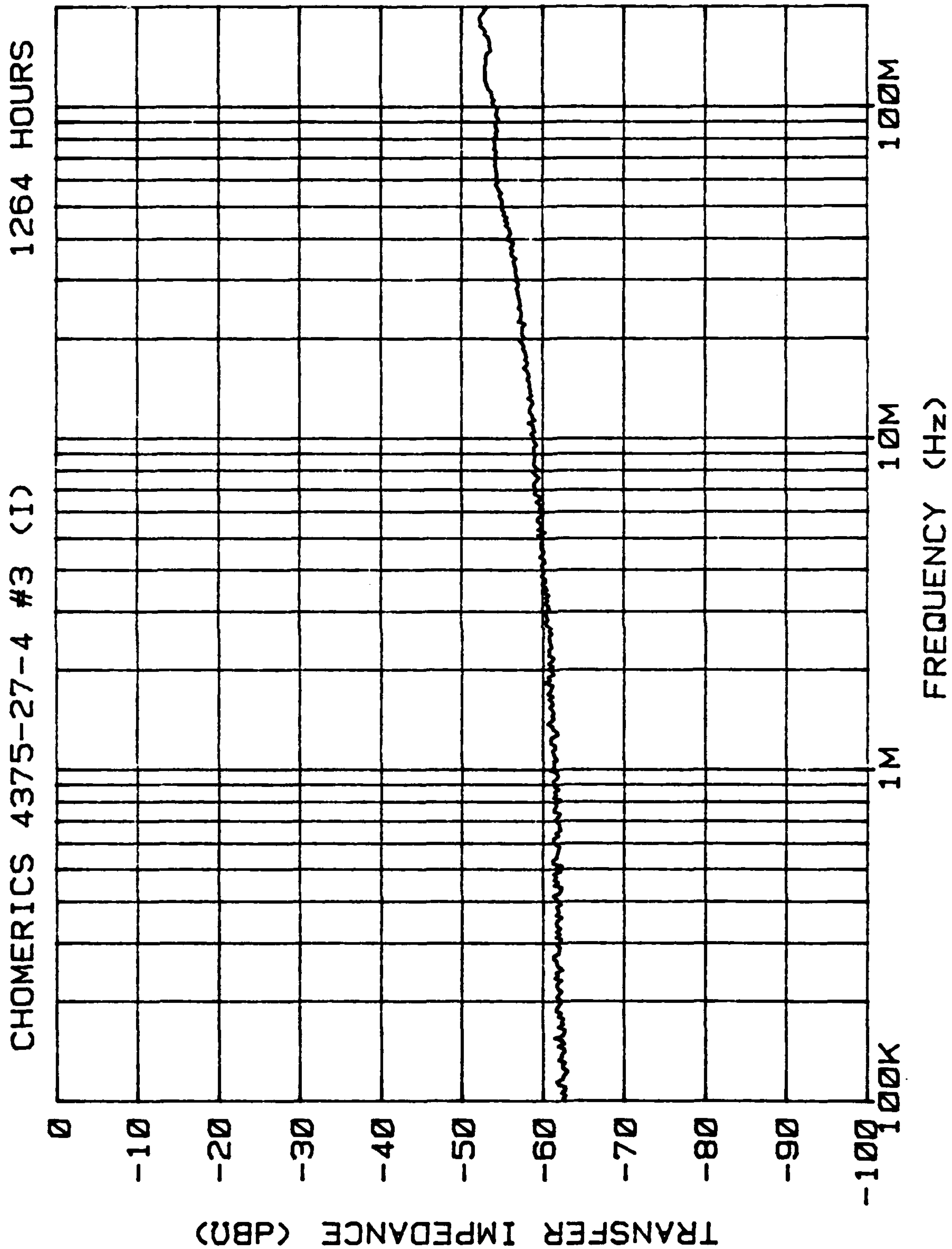
Test Sample Al, 1264 Hrs.



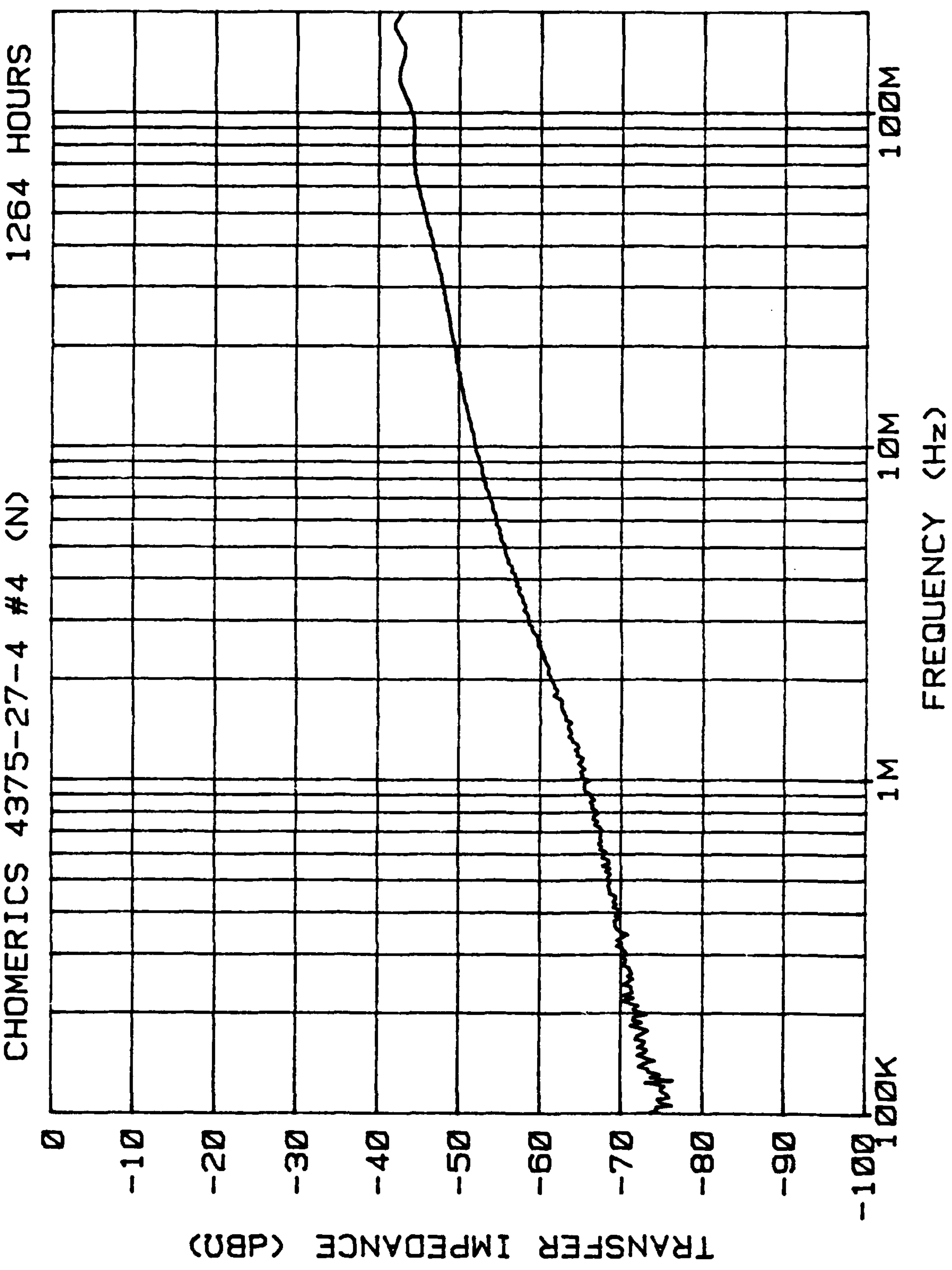
Test Sample A2, 1264 Hrs.



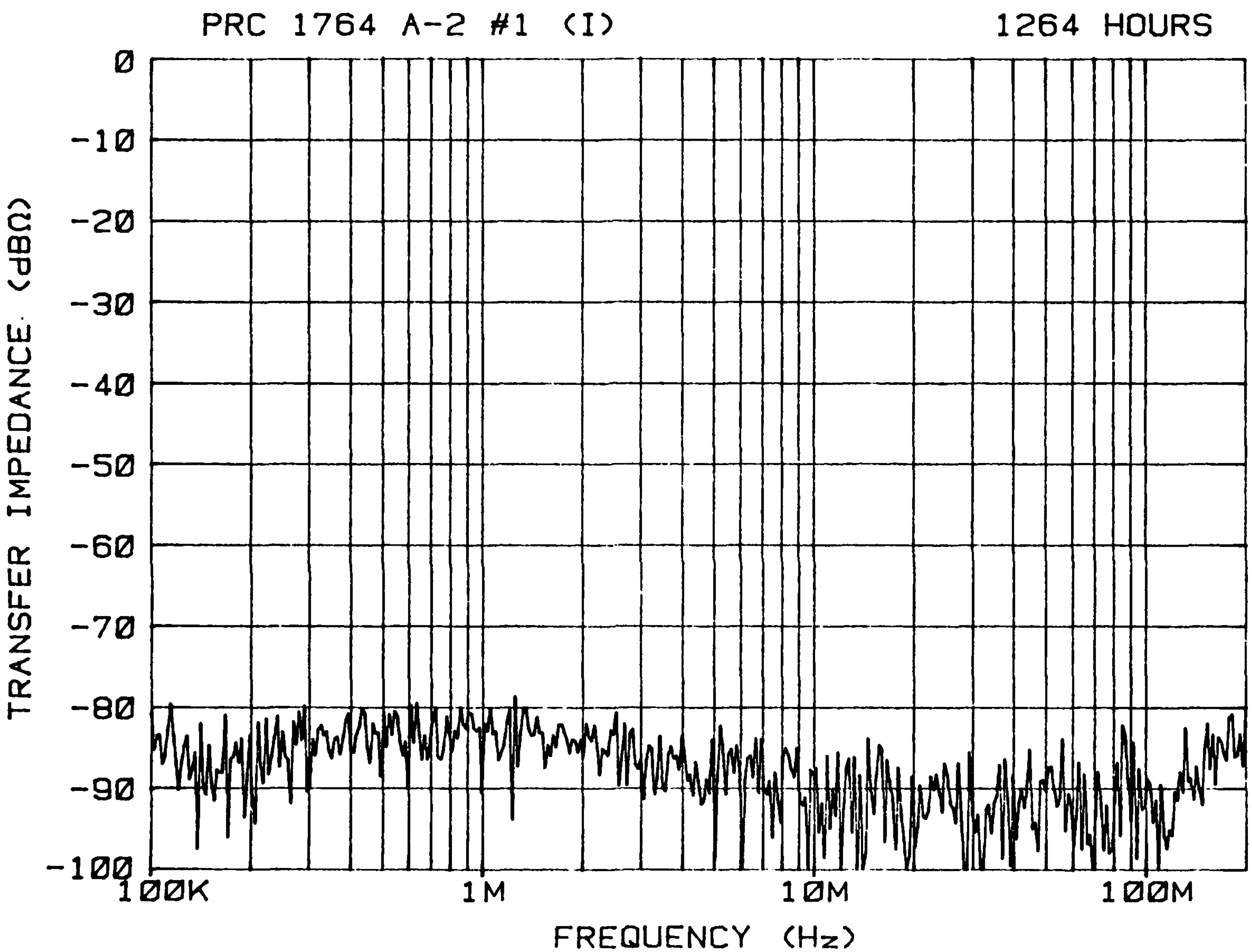
Test Sample A3, 1264 Hrs.



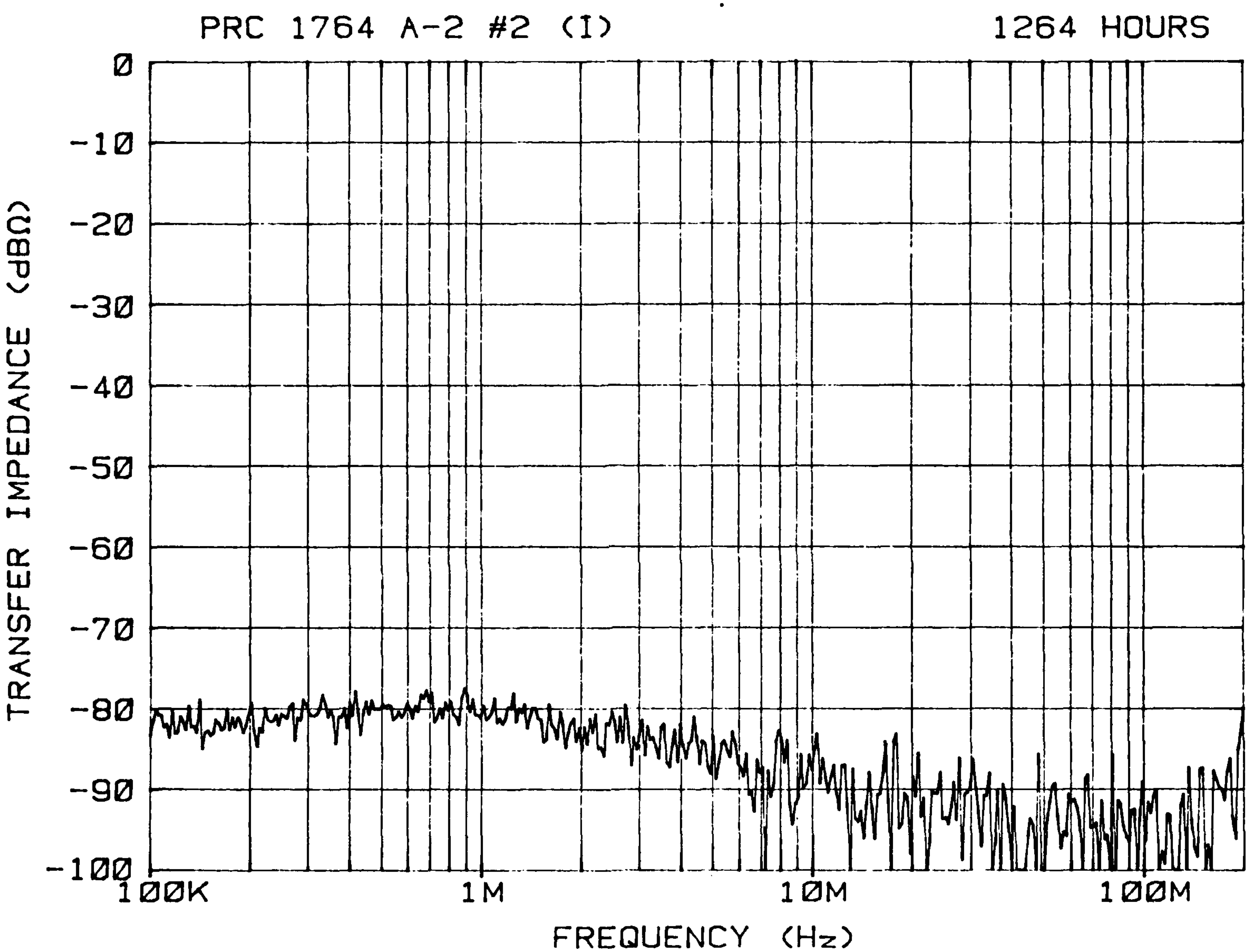
Test Sample A4, 1264 Hrs.



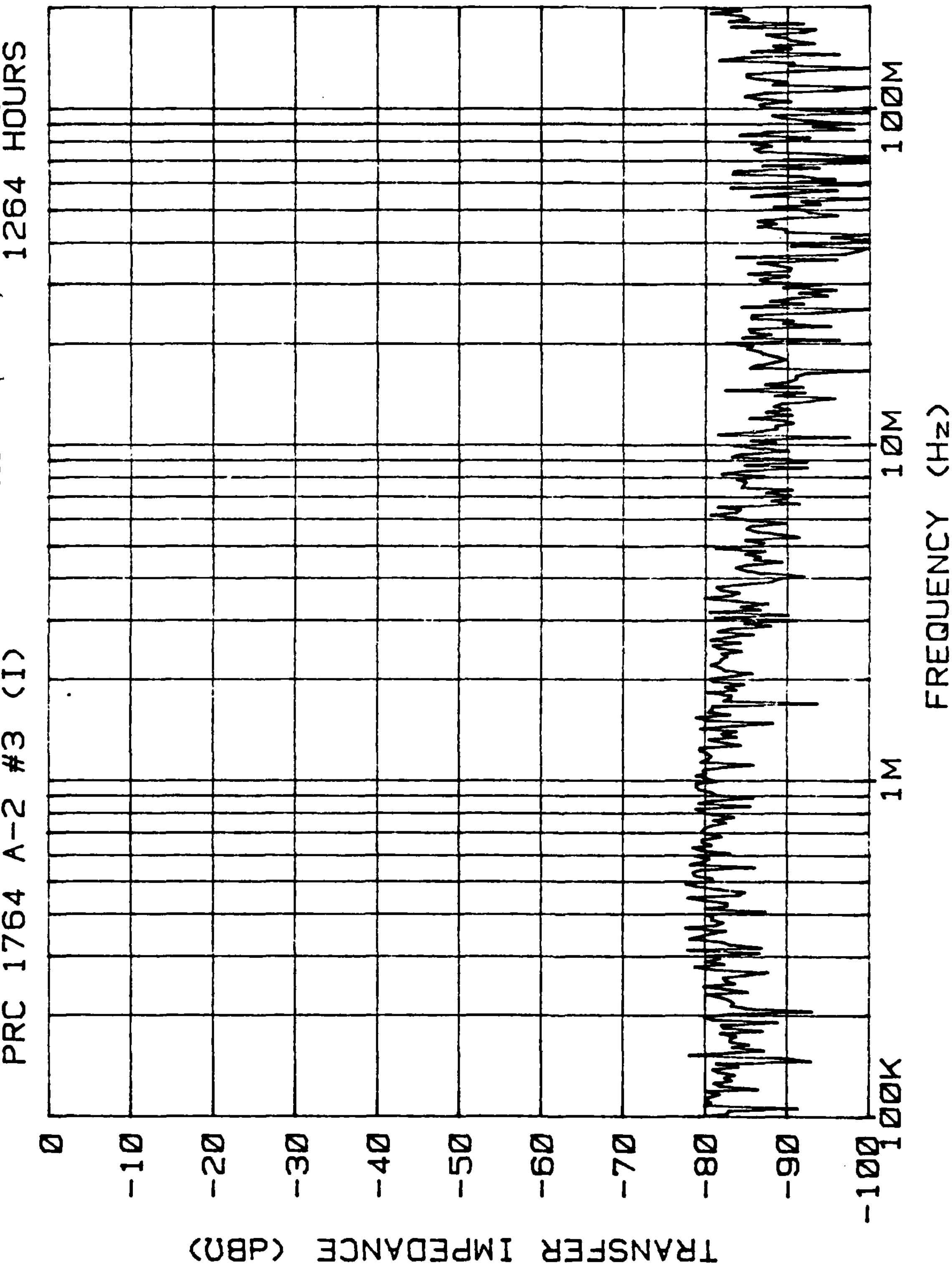
Test Sample Cl, 1264 Hrs.



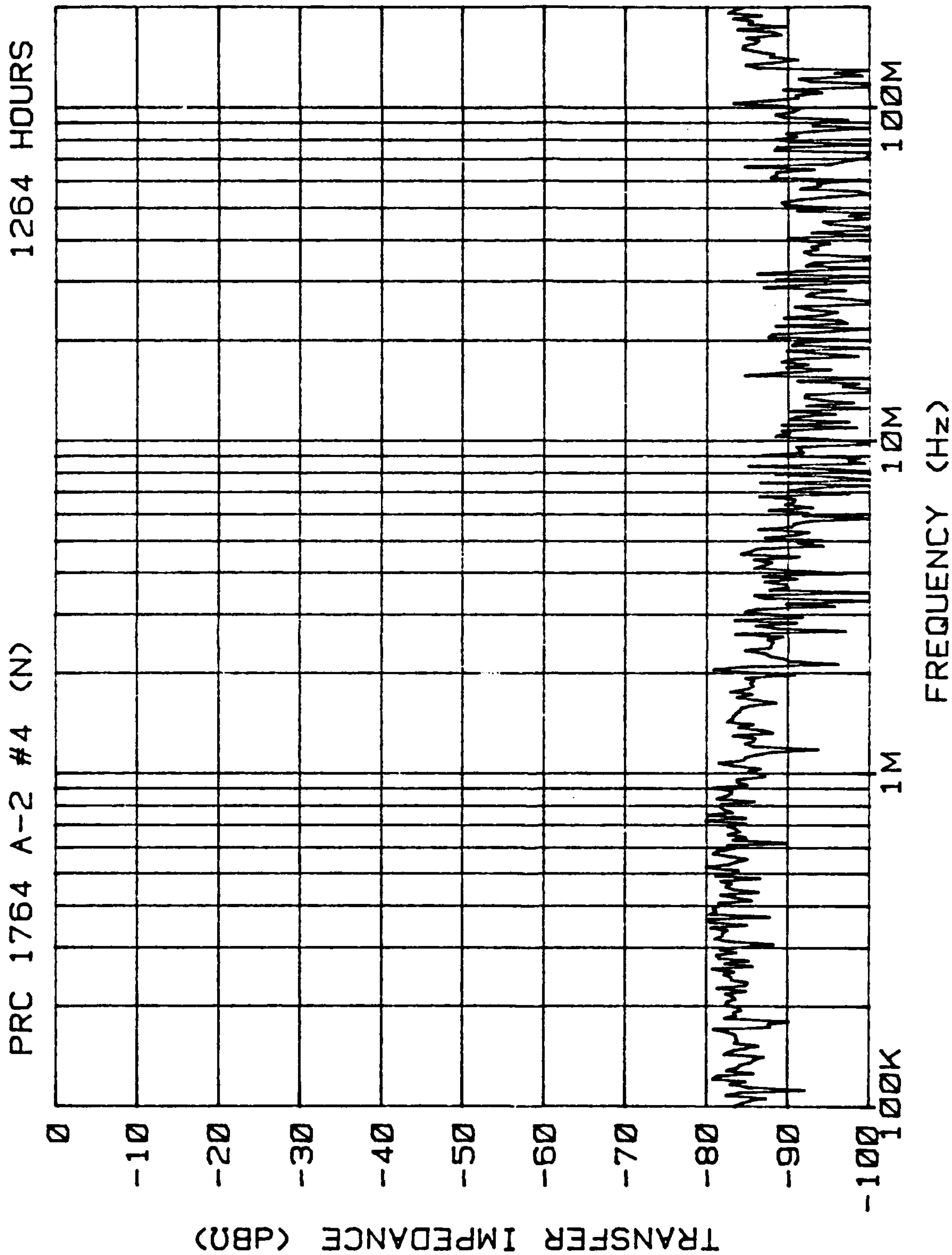
Test Sample C2, 1264 Hrs.



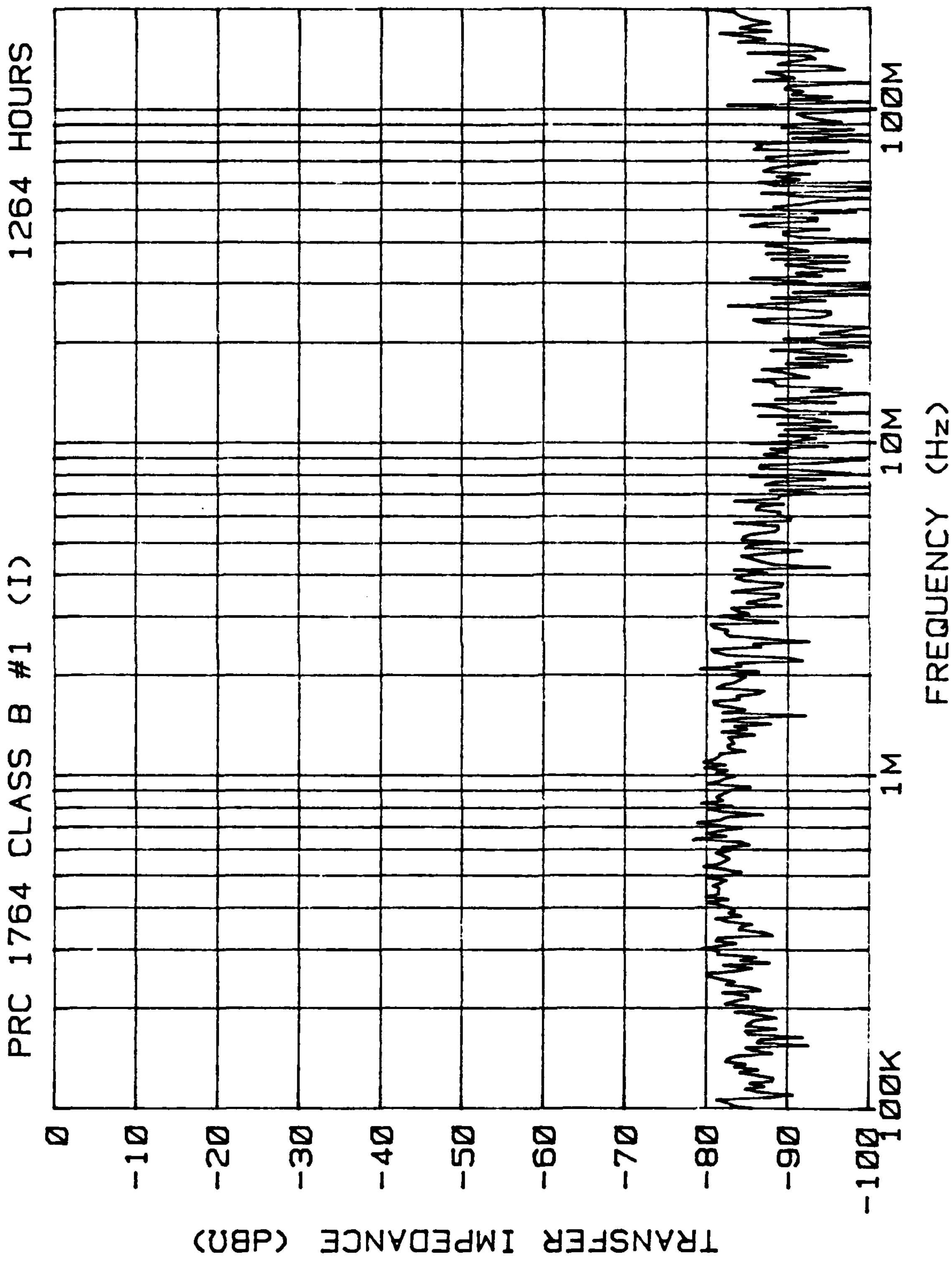
Test Sample C3, 1264 Hrs.



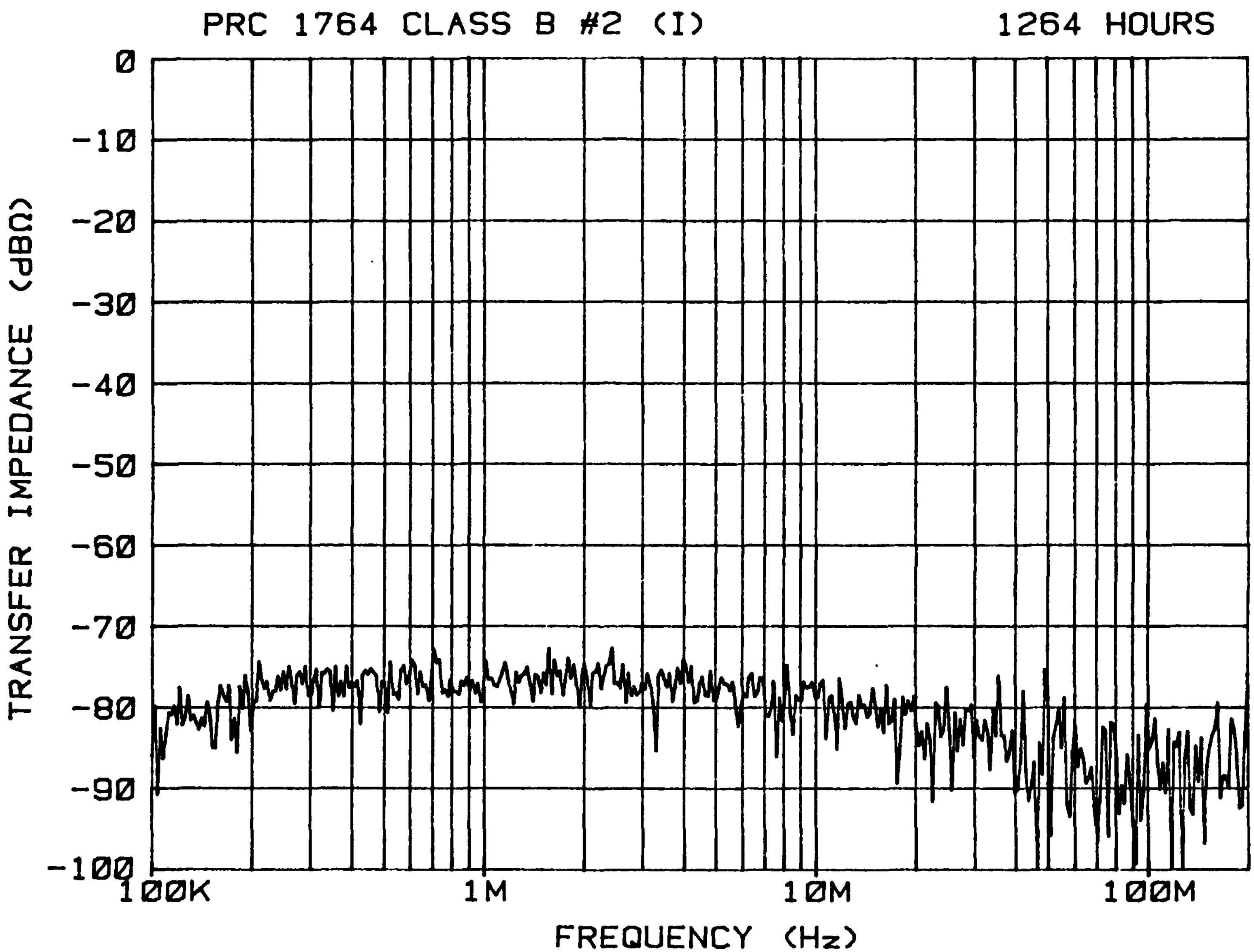
Test Sample C4, 1264 Hrs.



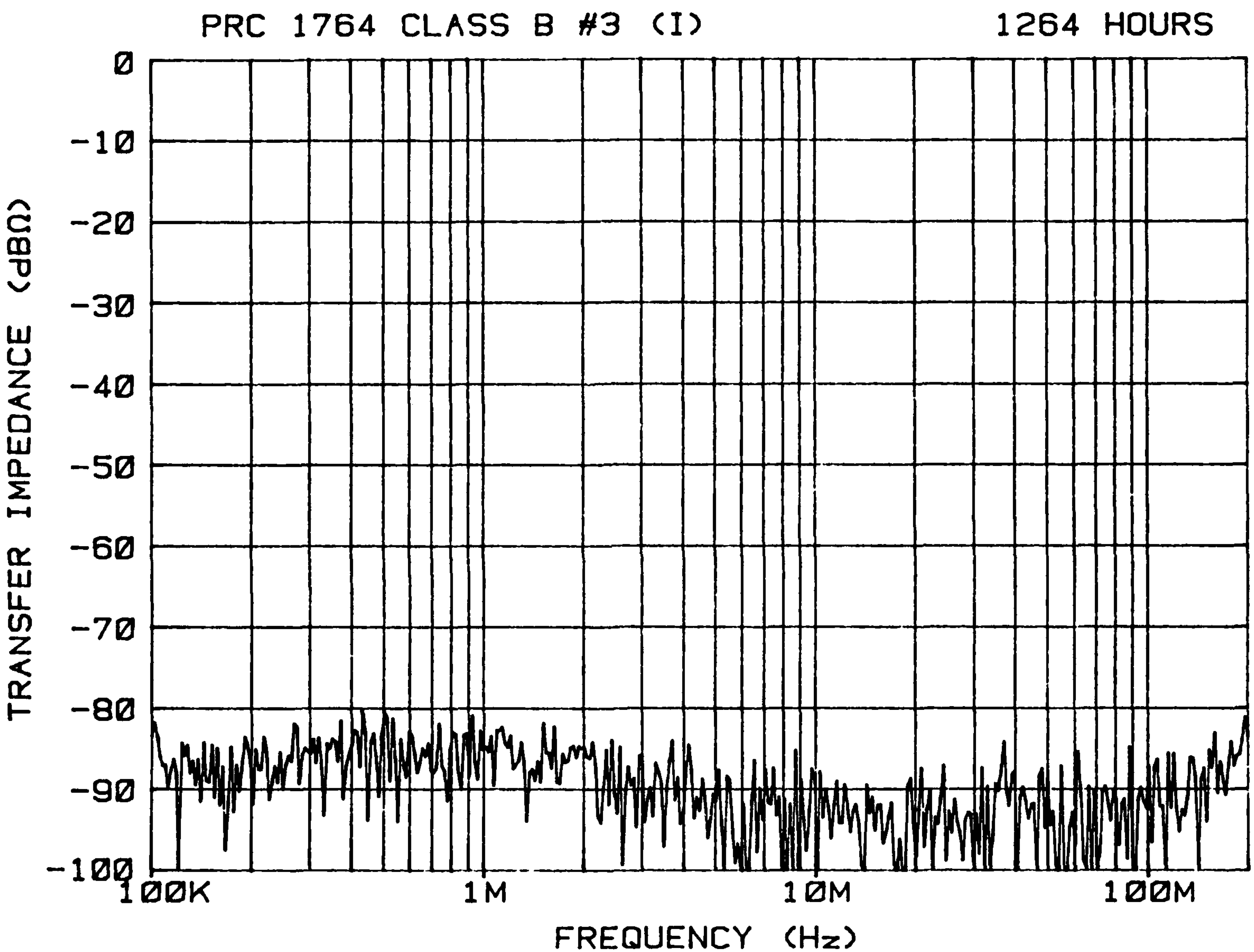
Test Sample D1, 1264 Hrs.



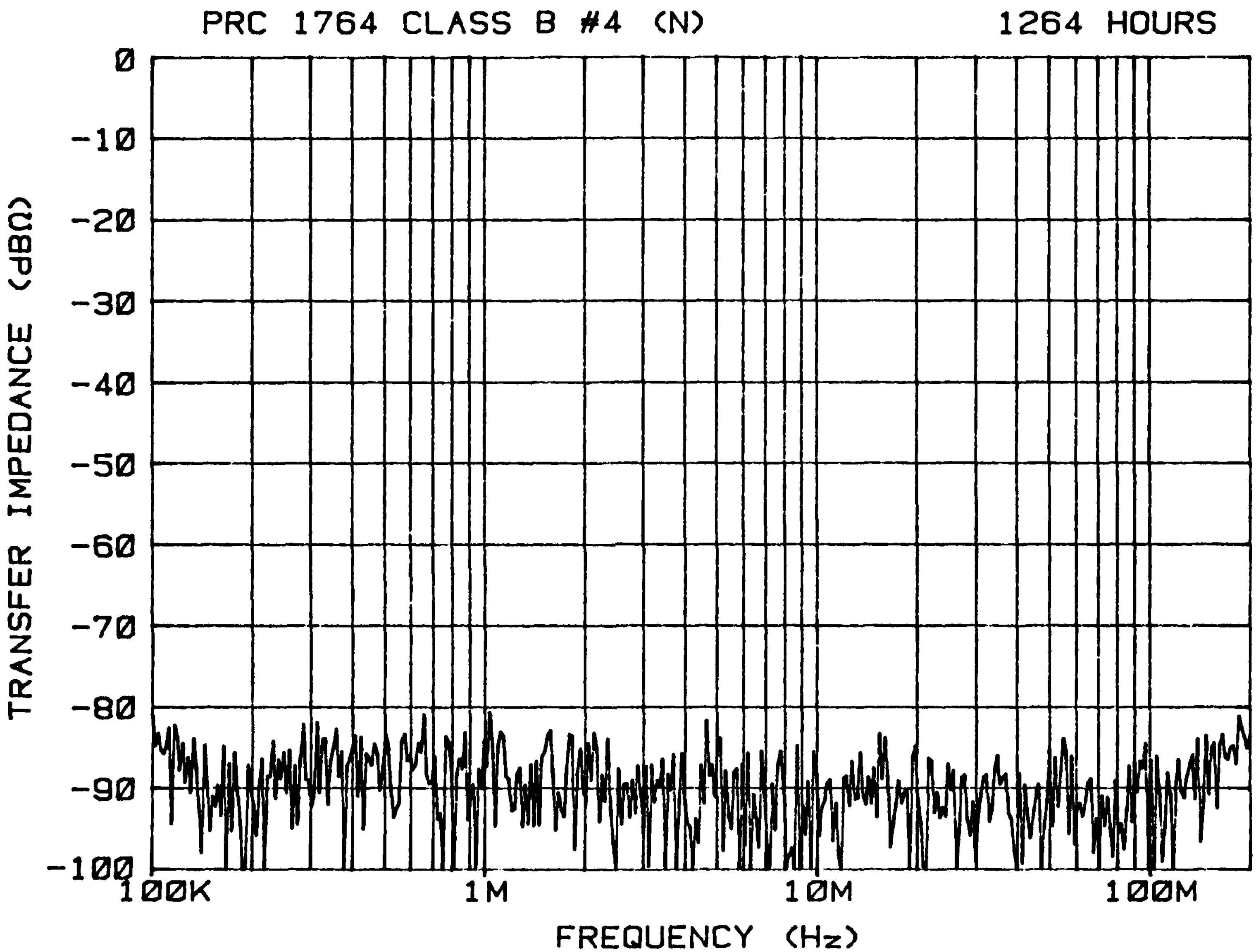
Test Sample D2, 1264 Hrs.



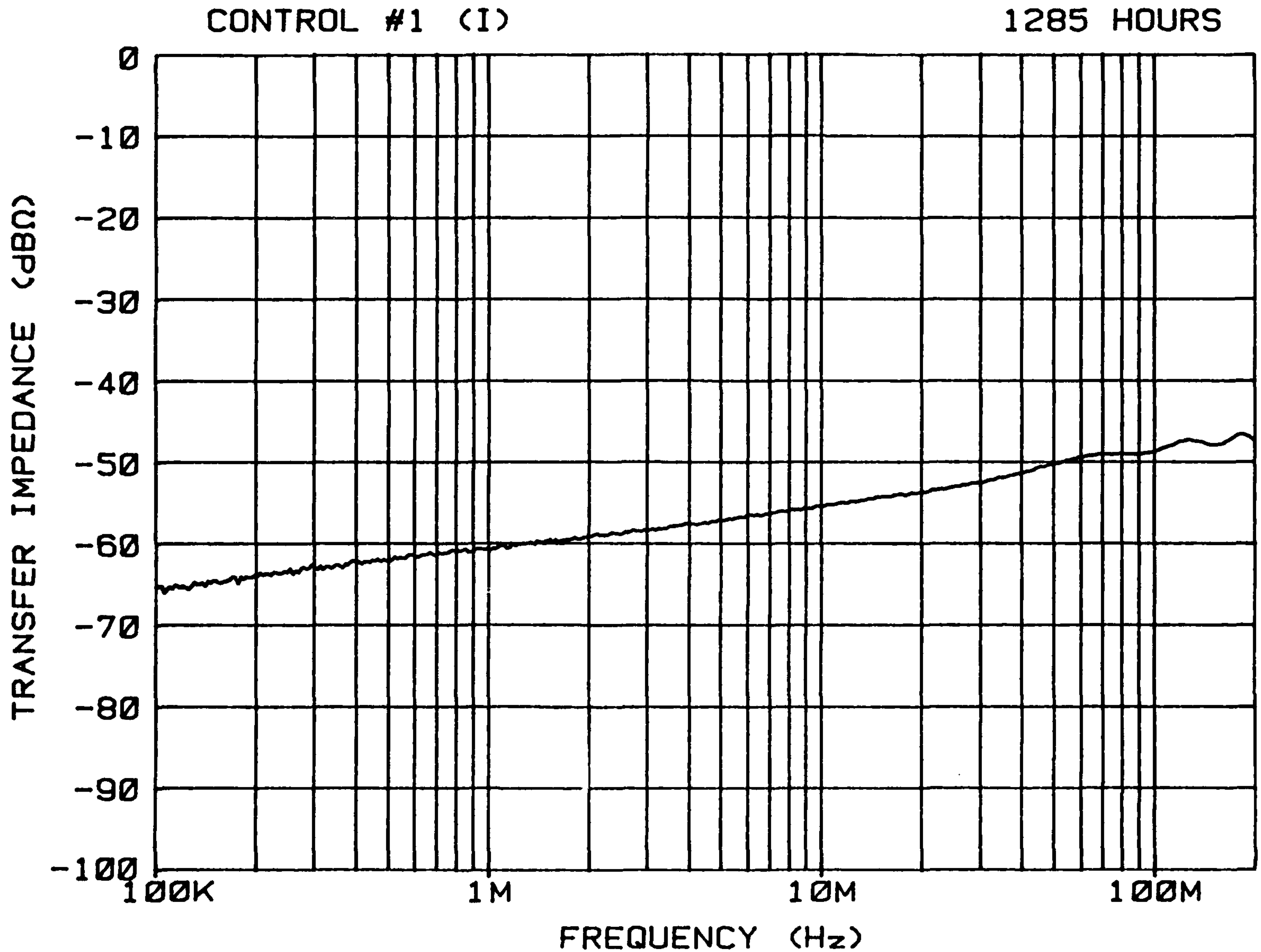
Test Sample D3, 1264 Hrs.



Test Sample D4, 1264 Hrs.

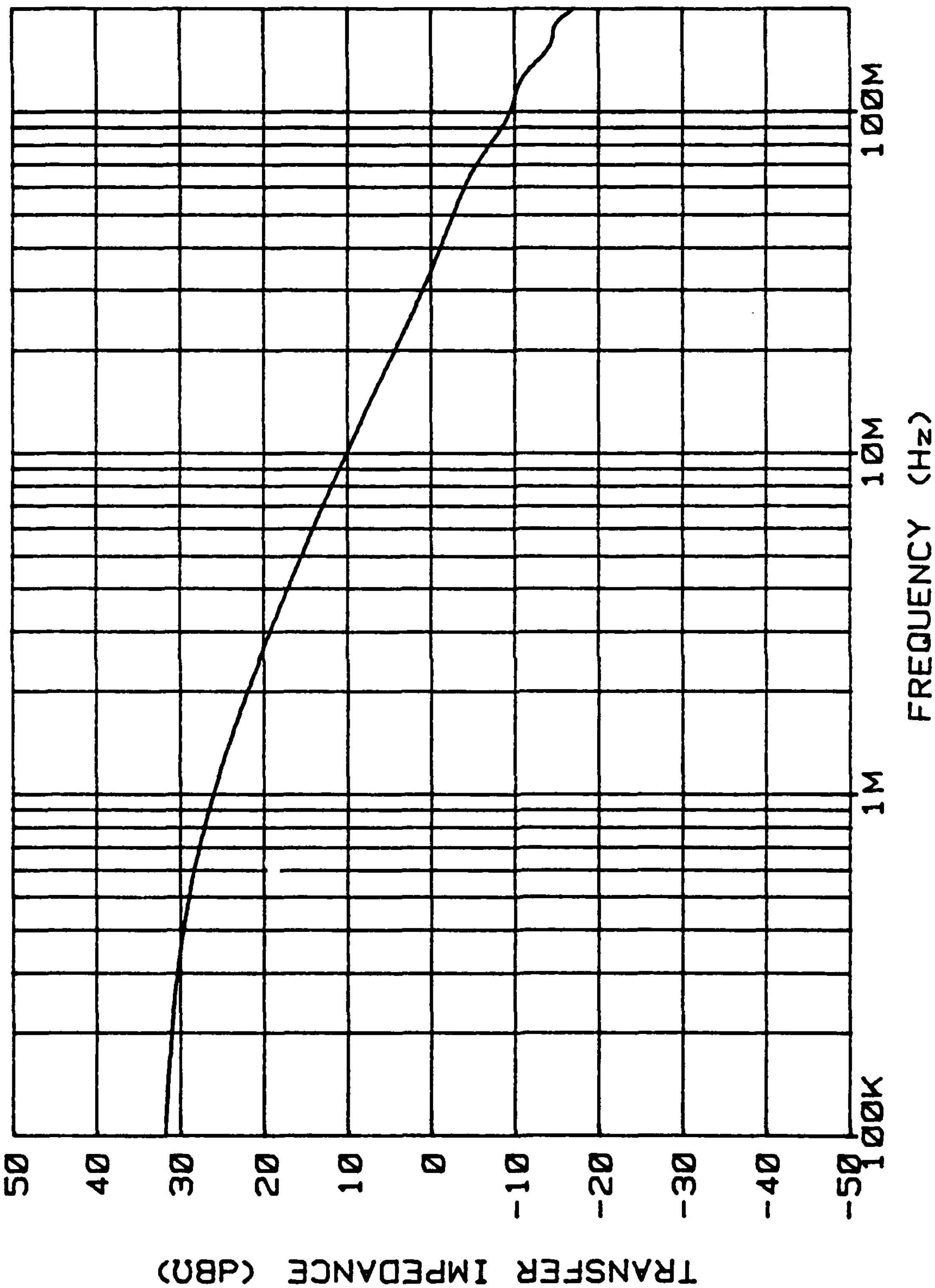


Test Sample B1, 1285 Hrs.

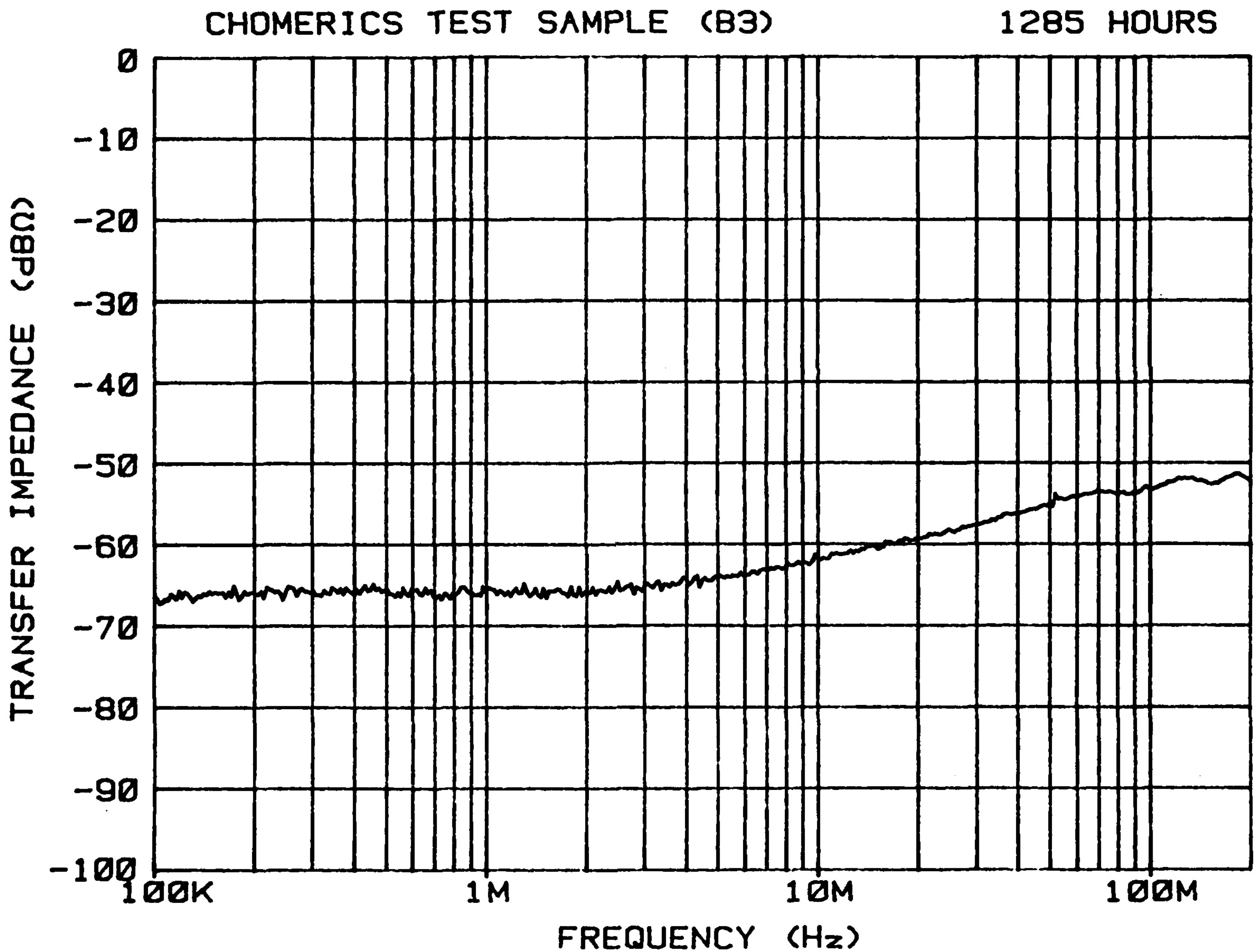


Test Sample B2, 1285 Hrs.

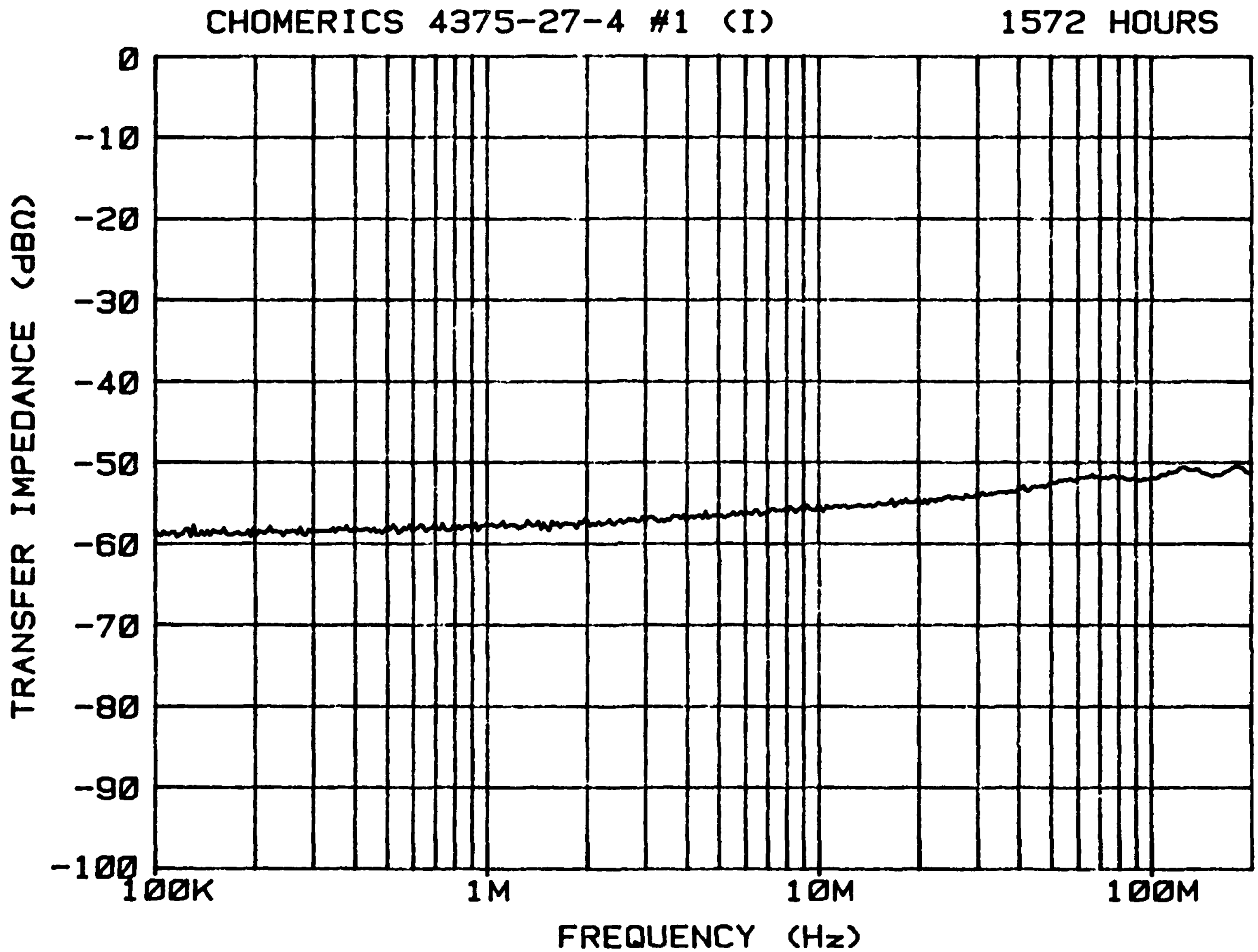
CONTROL #2 (N) 1285 HOURS



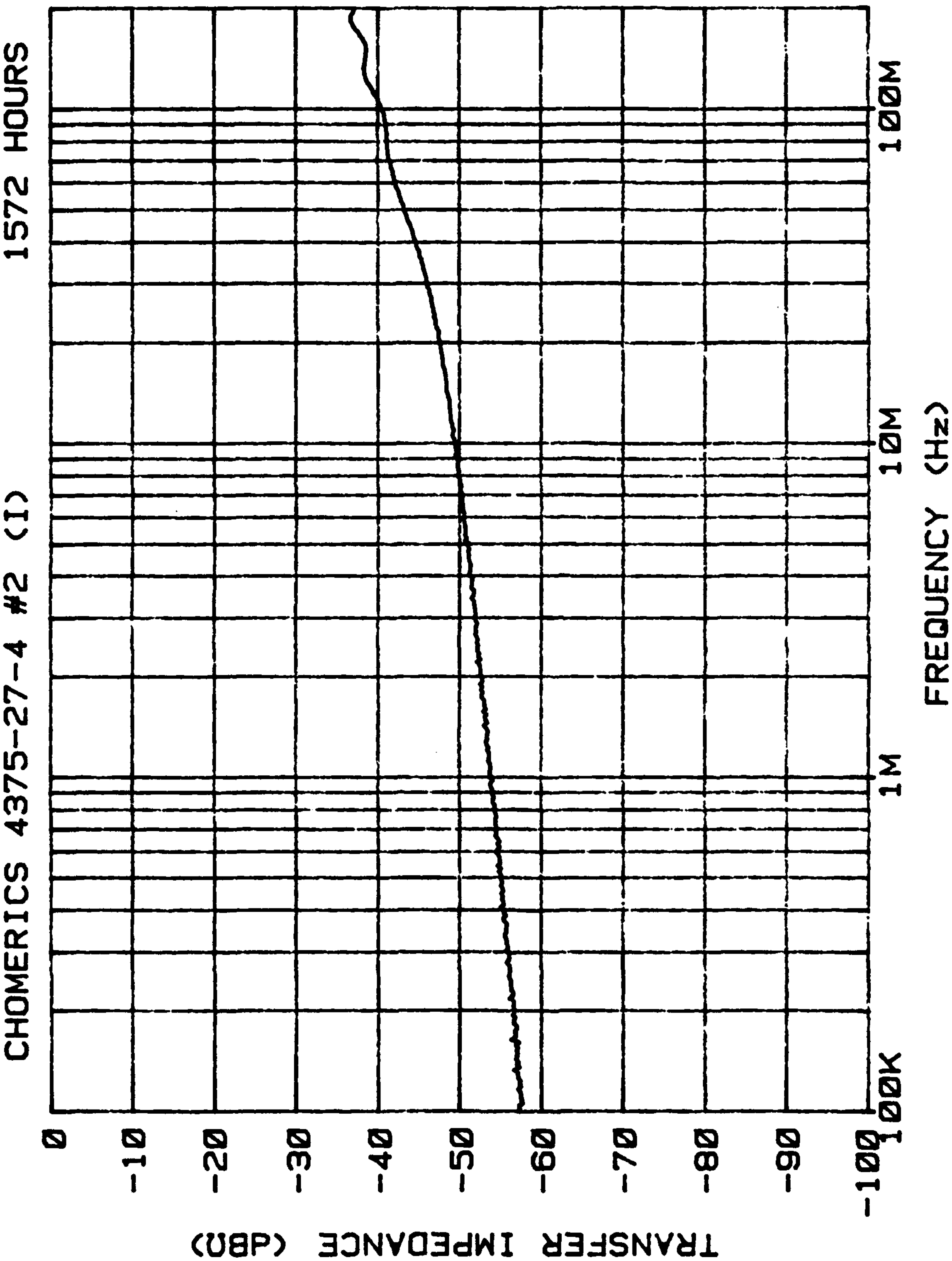
Test Sample B3, 1285 Hrs.



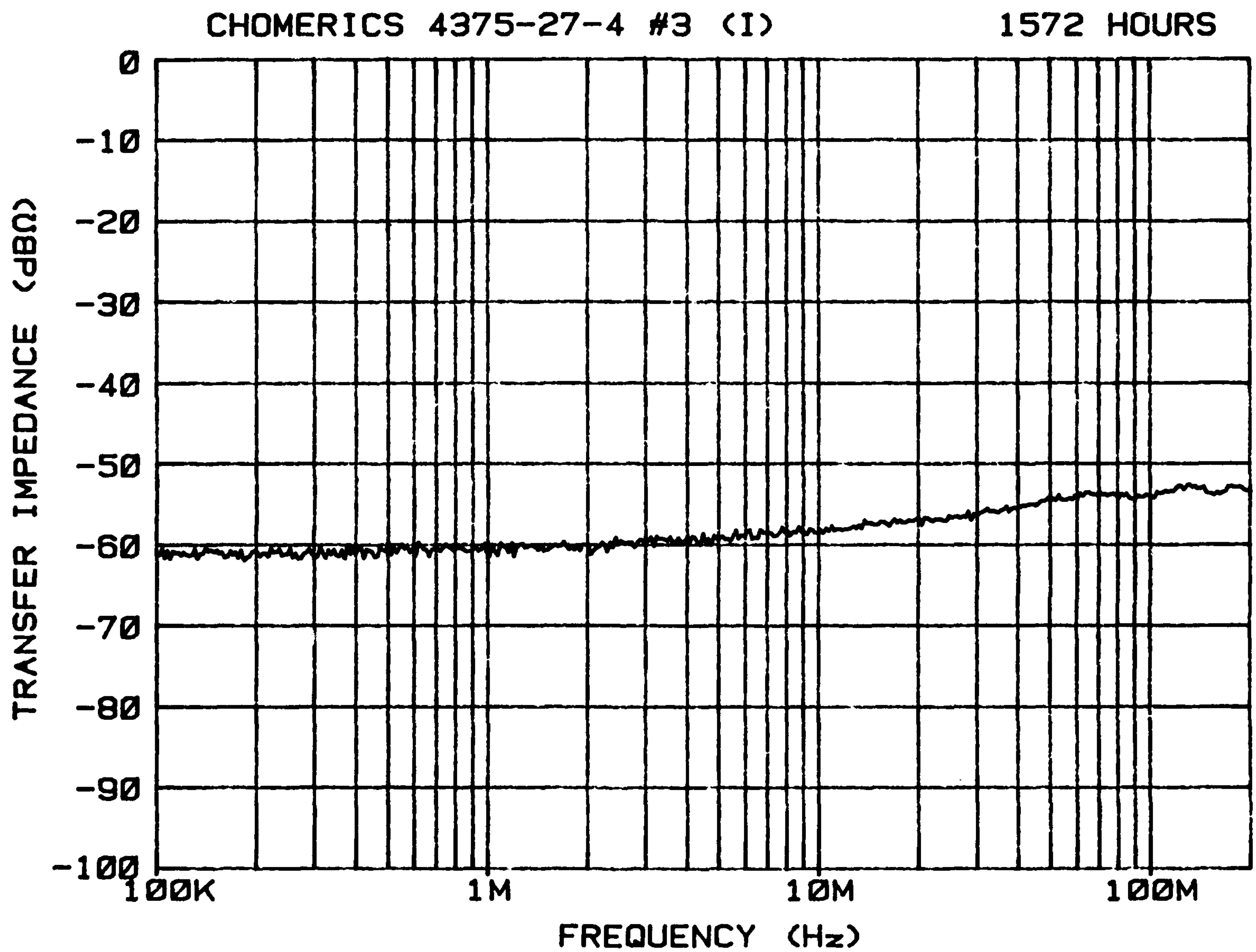
Test Sample Al, 1572 Hrs.



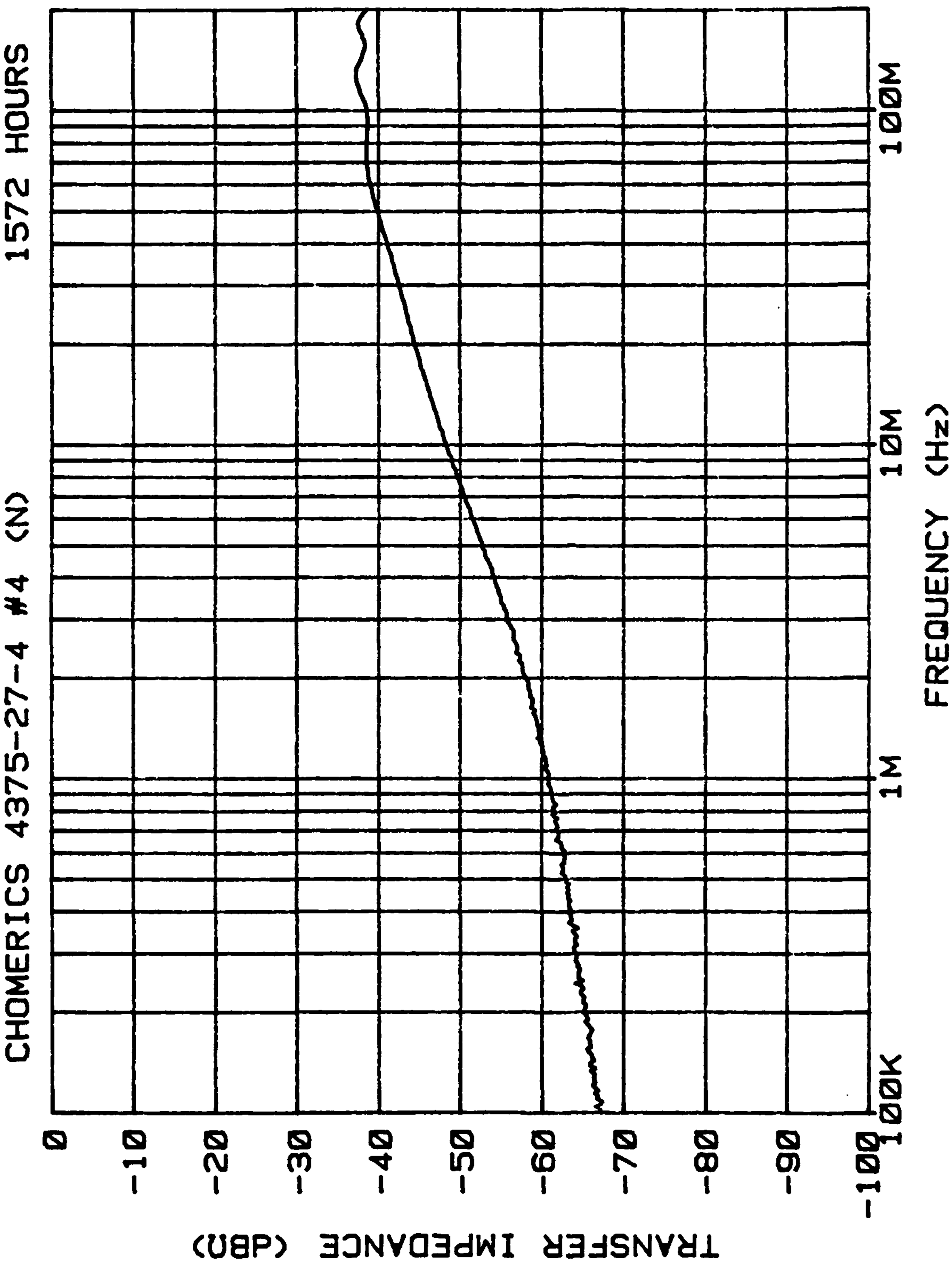
Test Sample A2, 1572 Hrs.

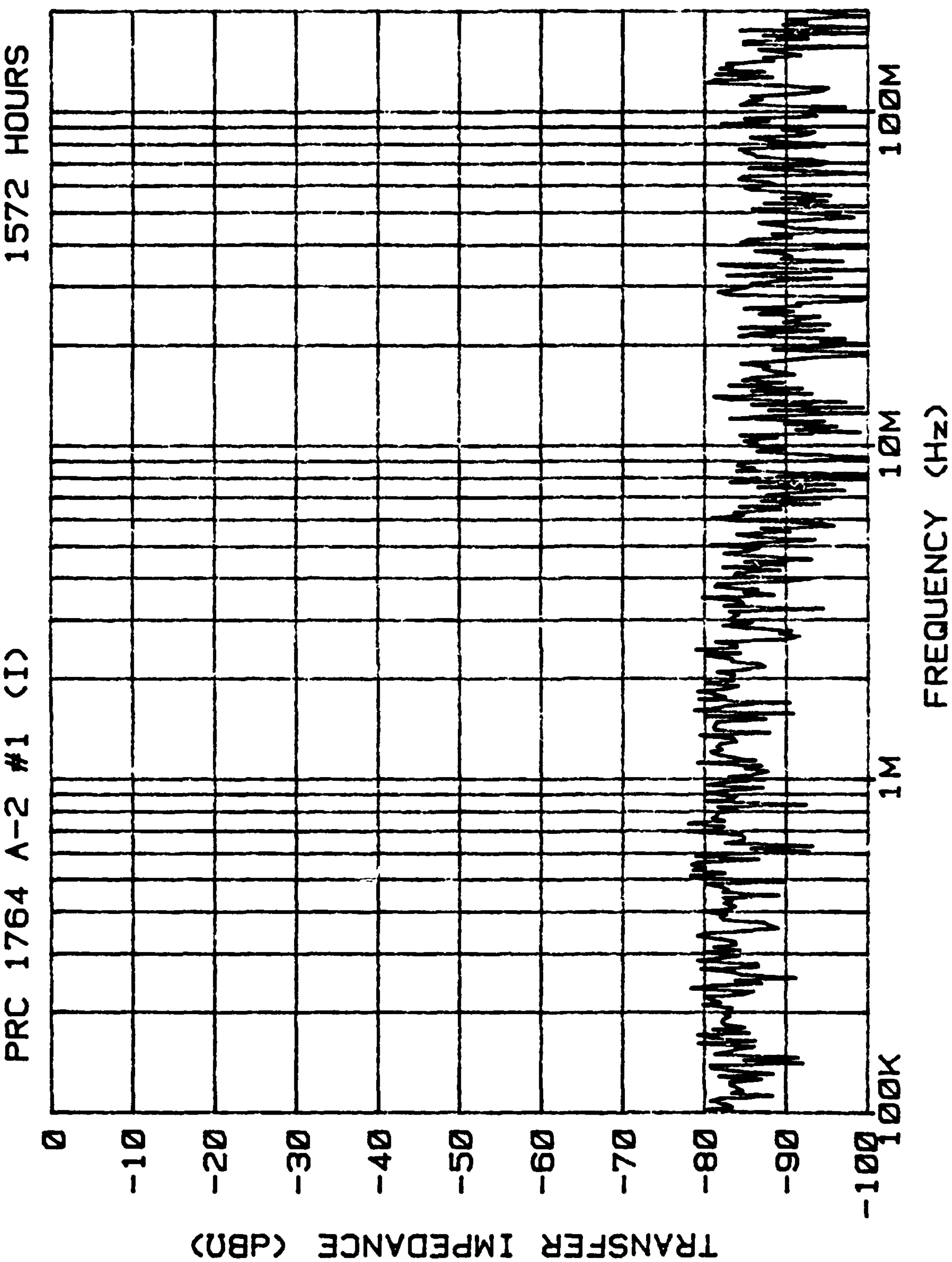


Test Sample A3, 1572 Hrs.



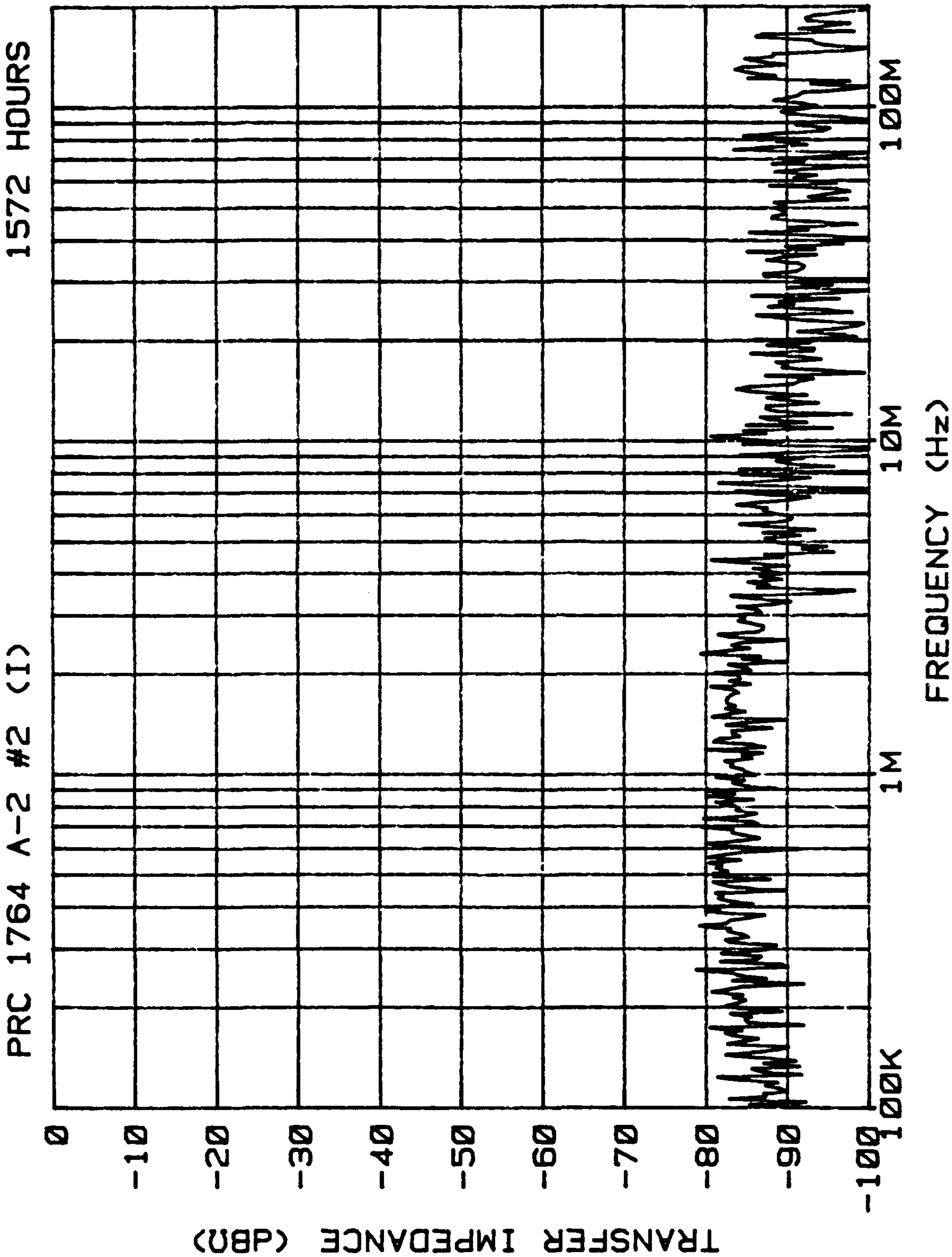
Test Sample A4,1572 Hrs.



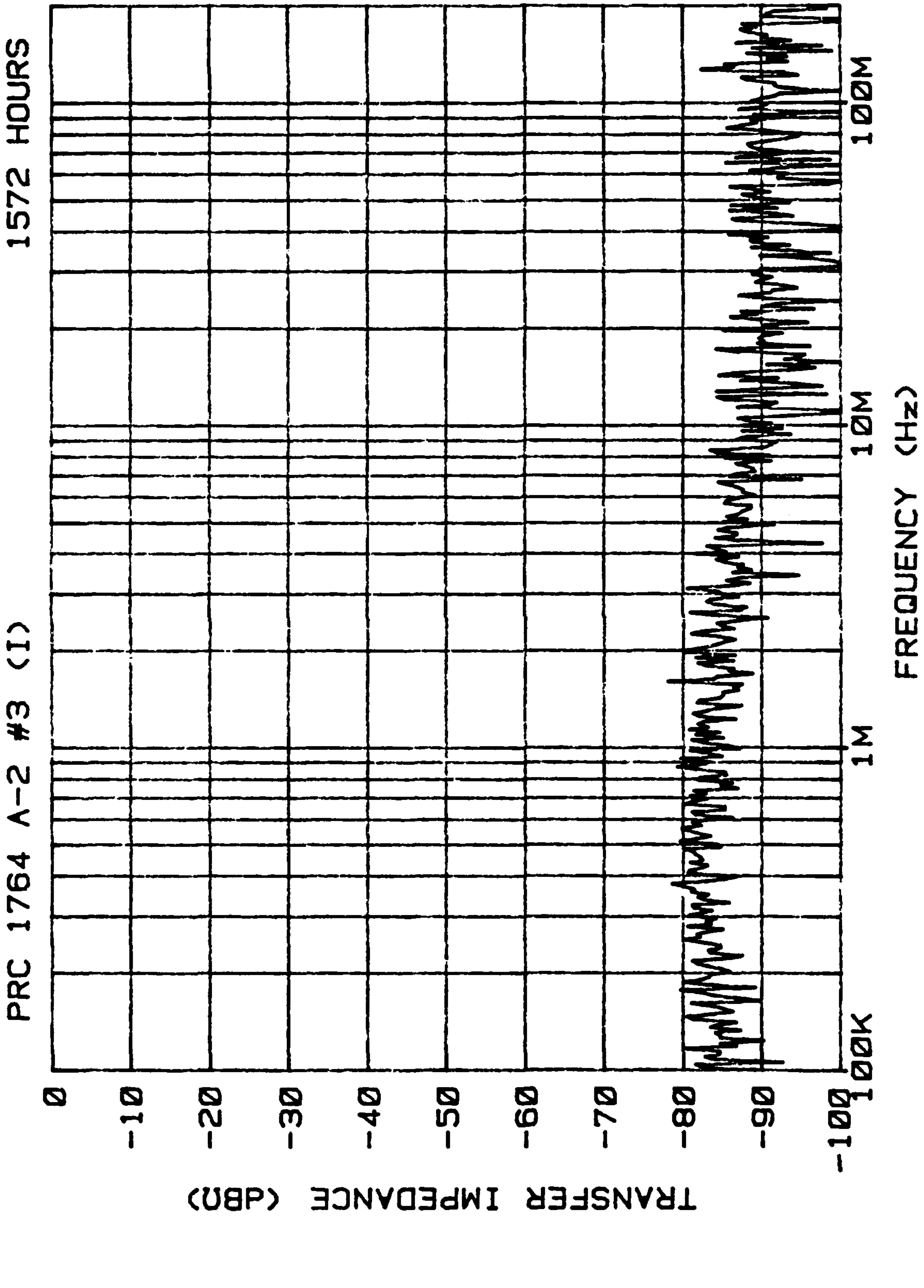


Test Sample C1, 1572 Hrs.

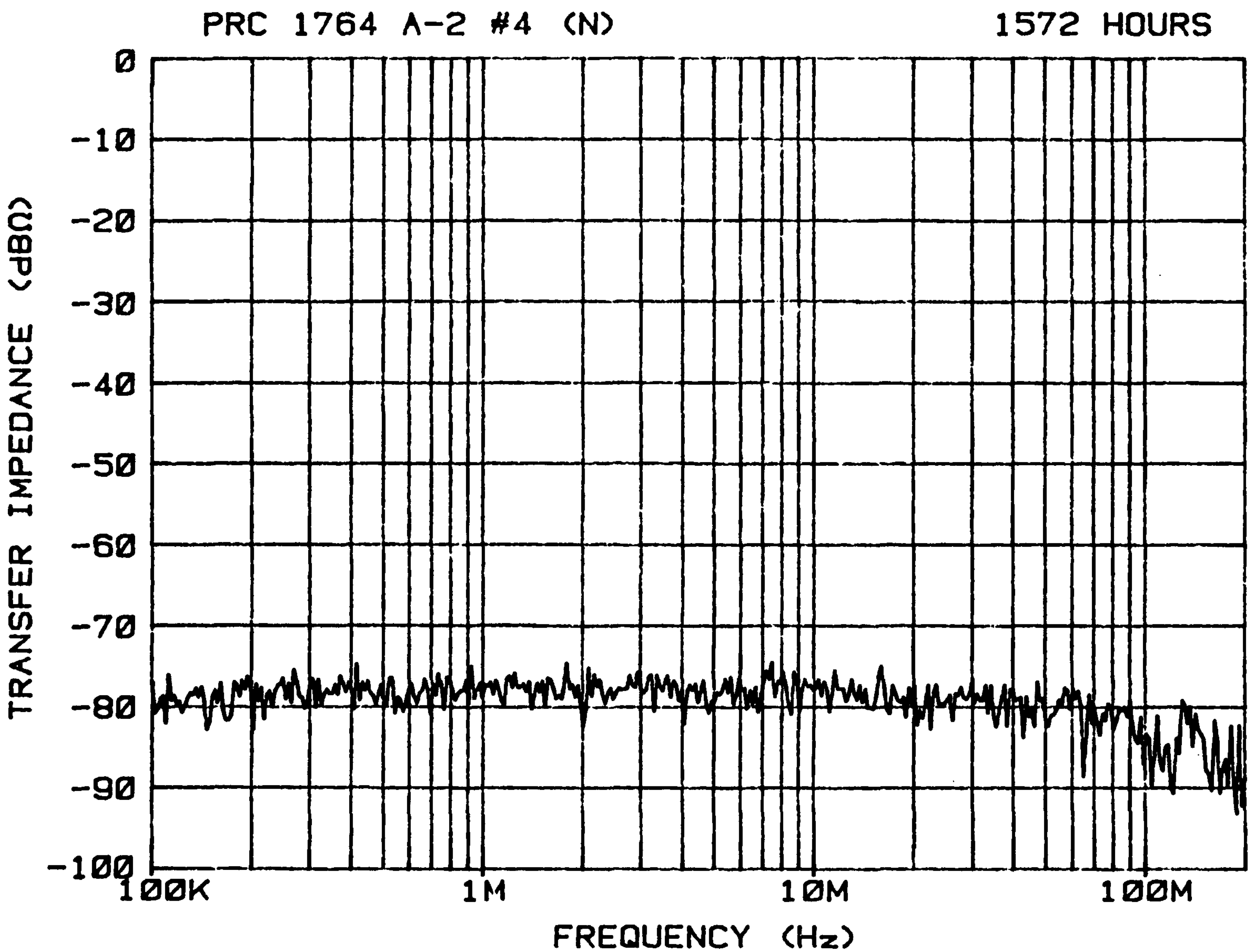
Test Sample A2, 1572 Hrs.



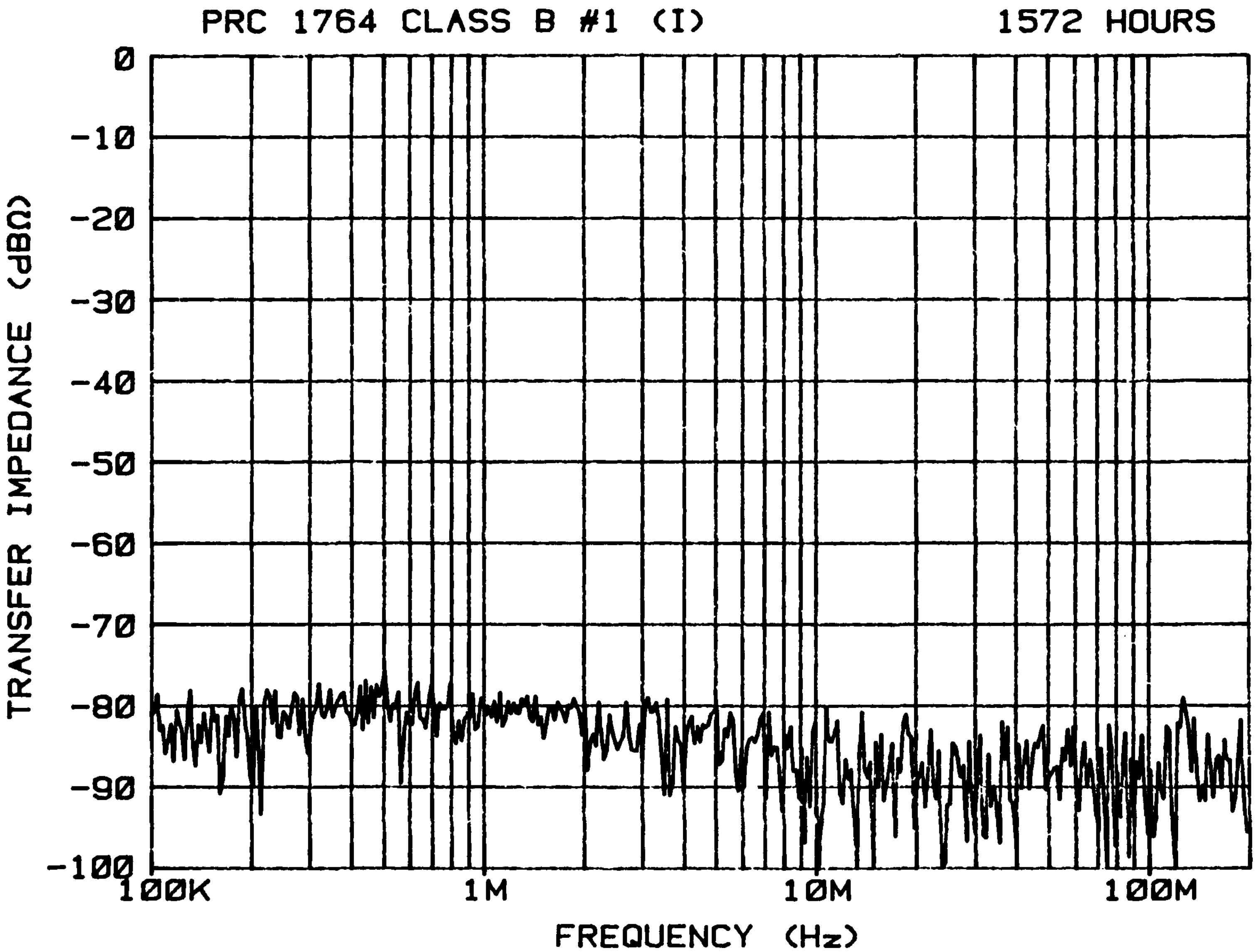
Test Sample C3, 1572 Hrs.



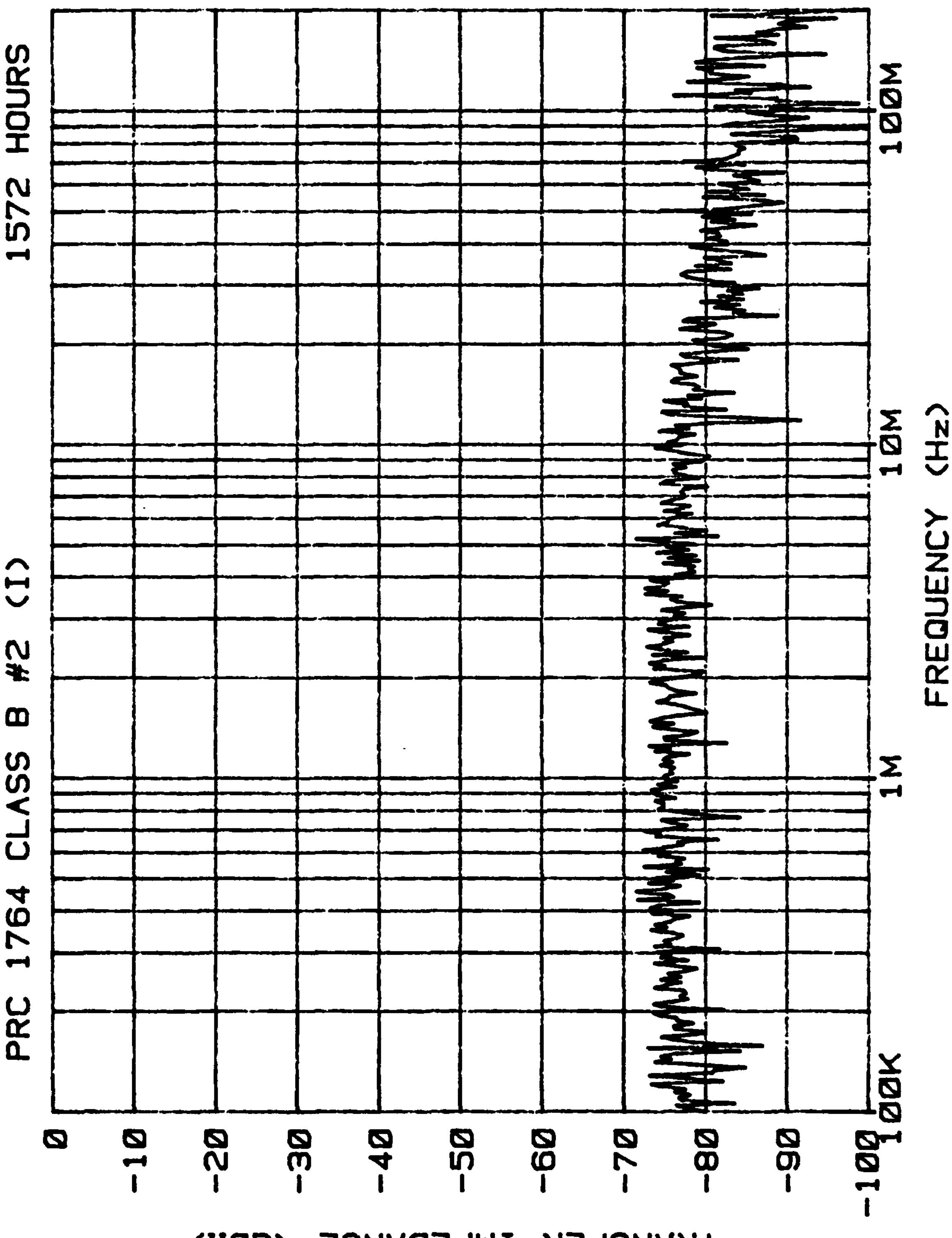
Test Sample C4, 1572 Hrs.



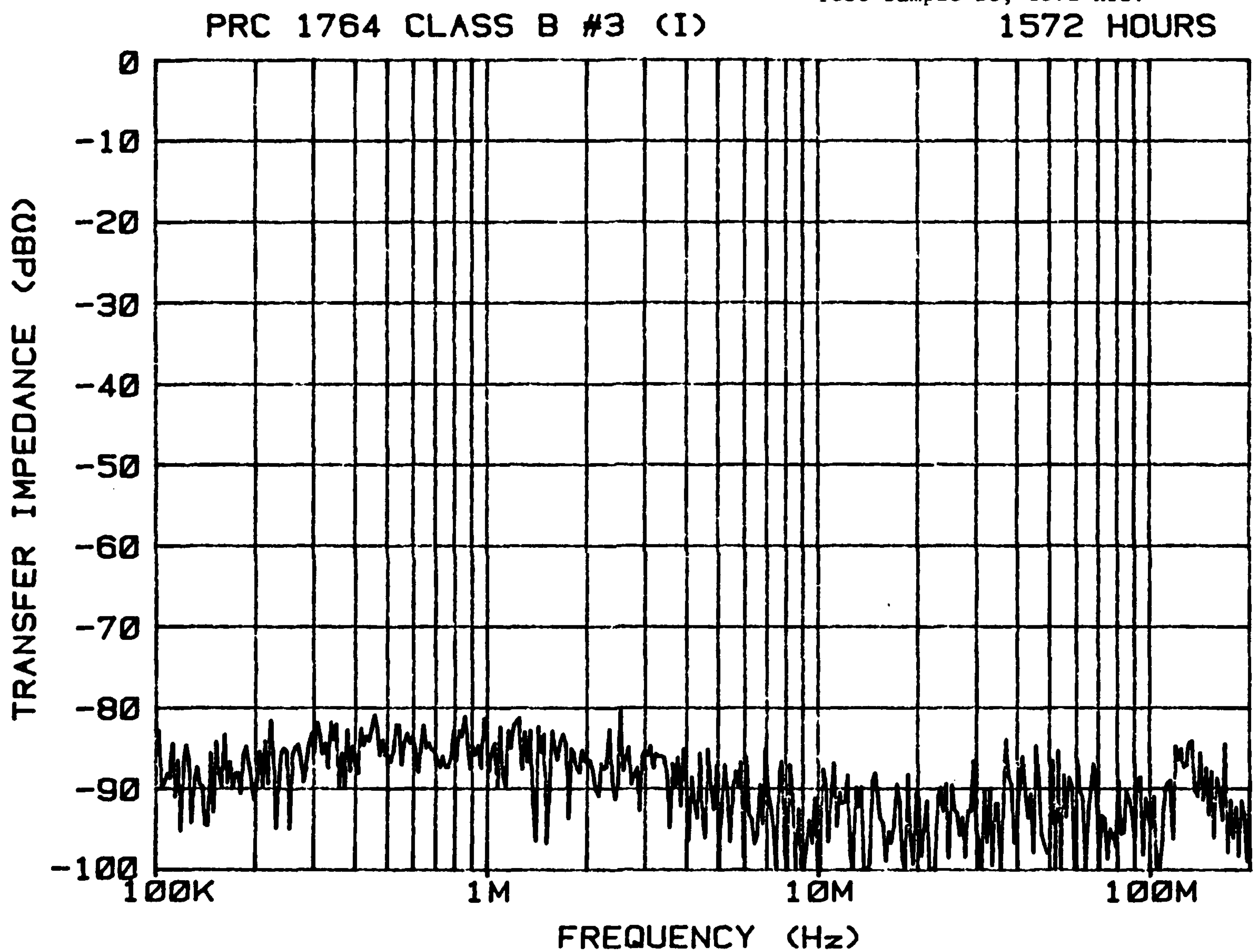
Test Sample D1, 1572 Hrs.



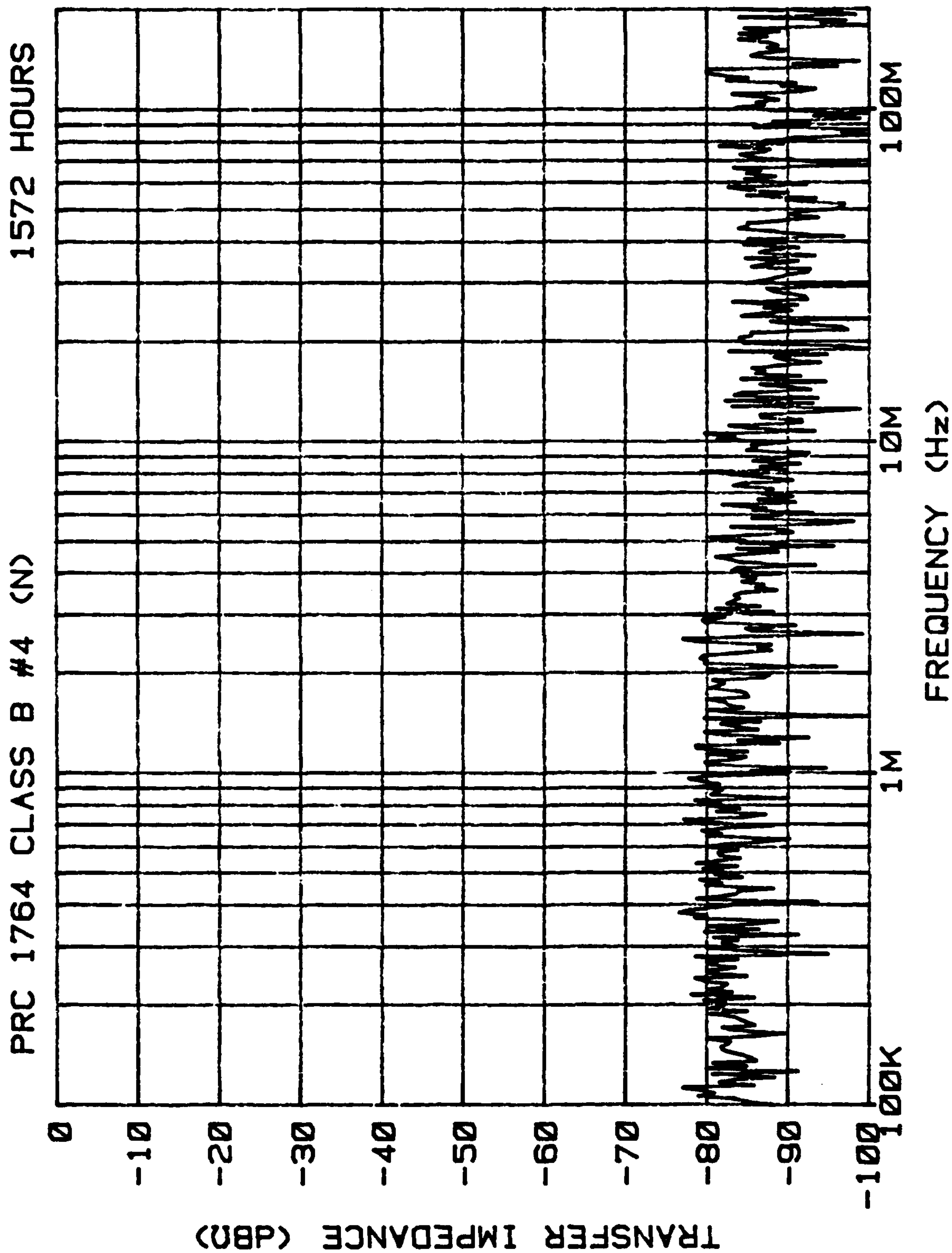
Test Sample D2, 1572 Hrs.



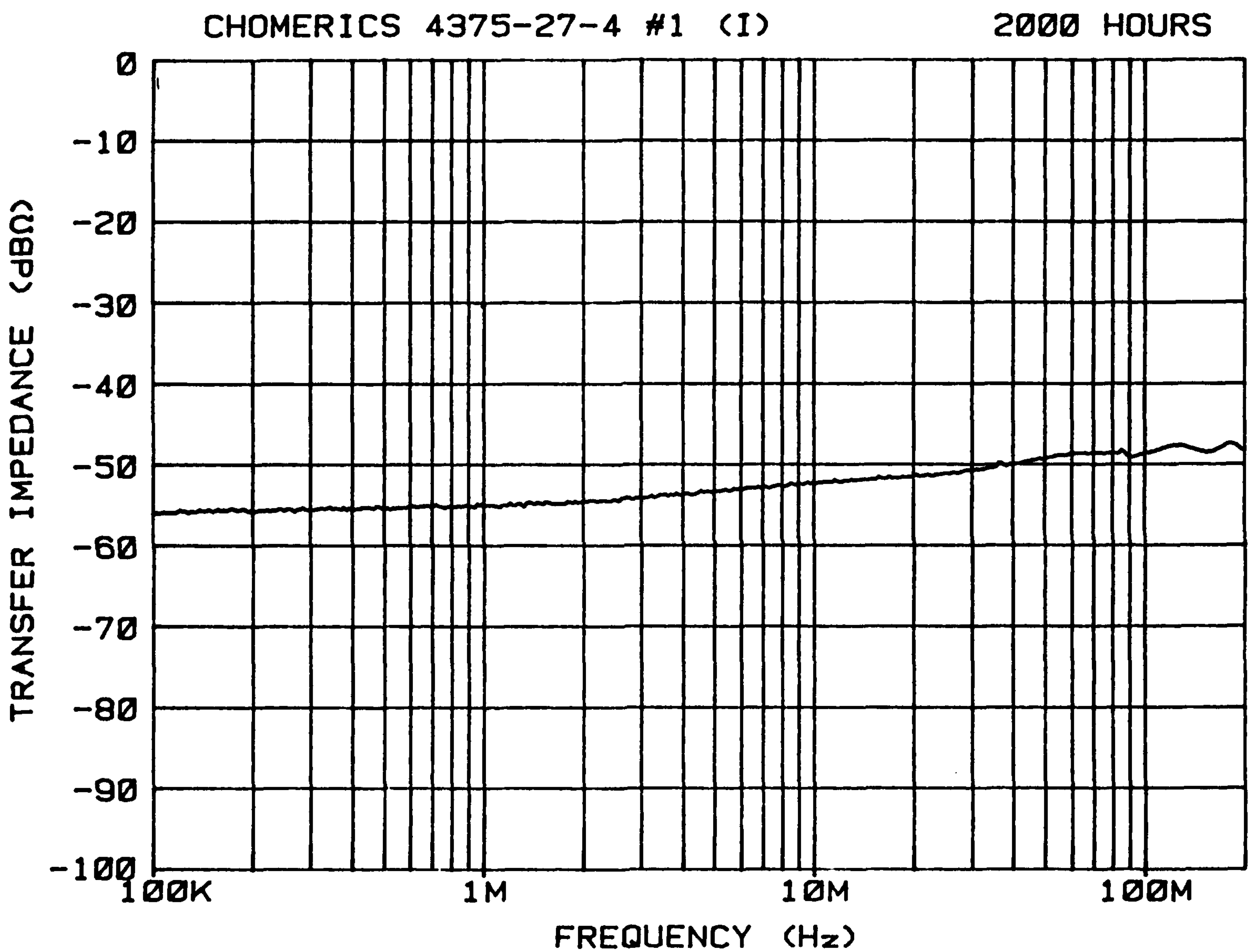
Test Sample D3, 1572 Hrs.



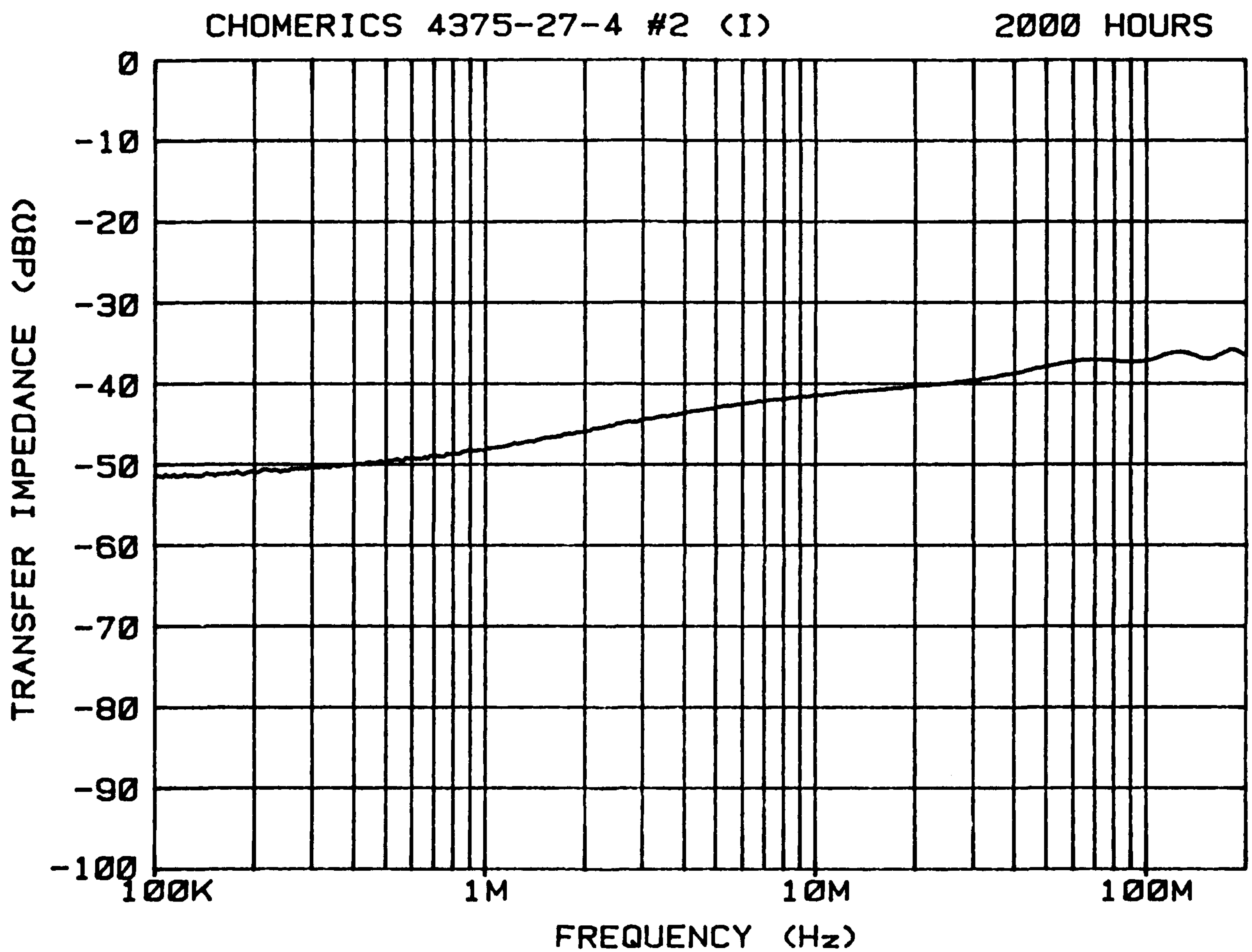
Test Sample B4, 1572 Hrs.



Test Sample Al, 2000 Hrs.

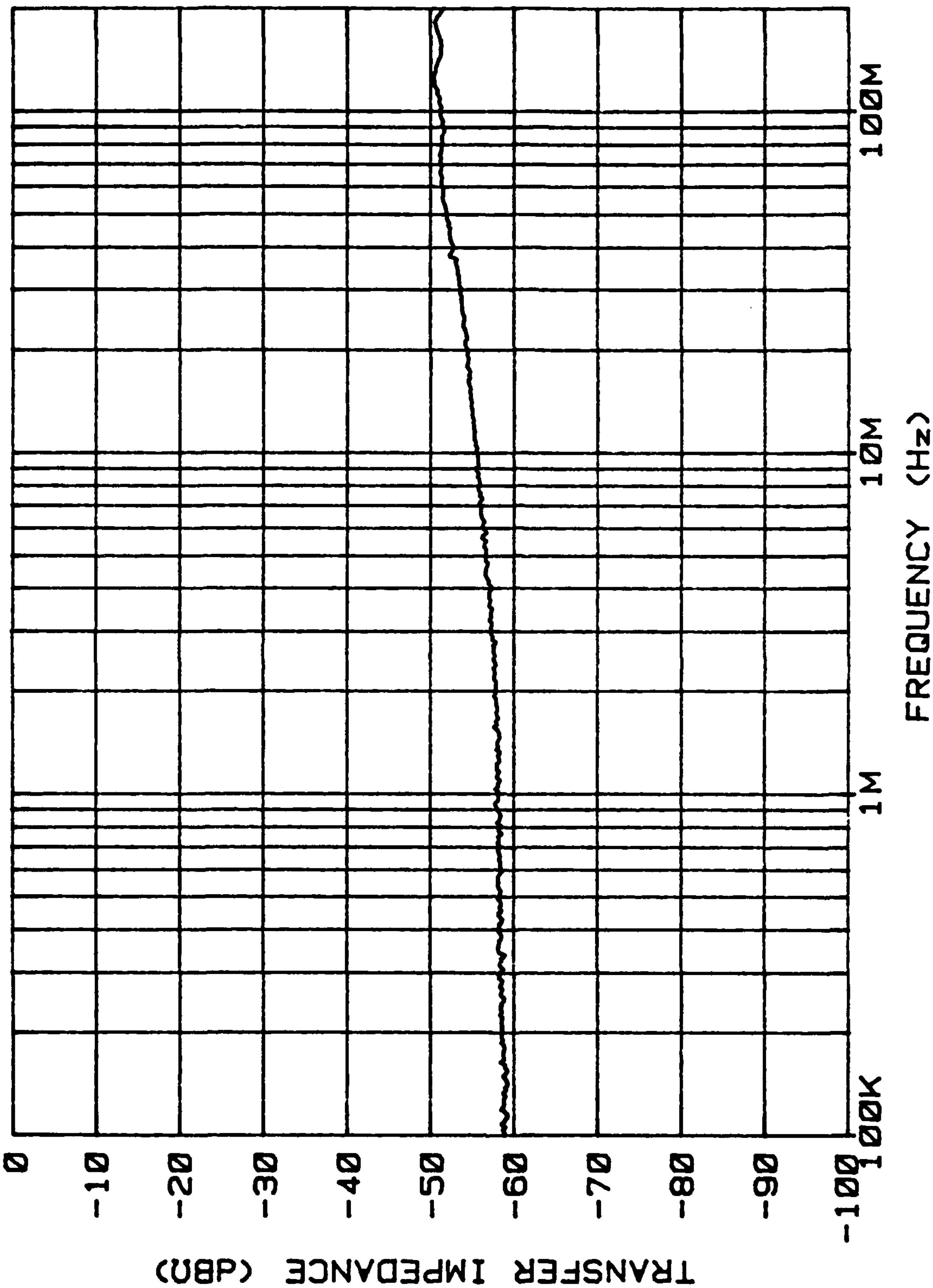


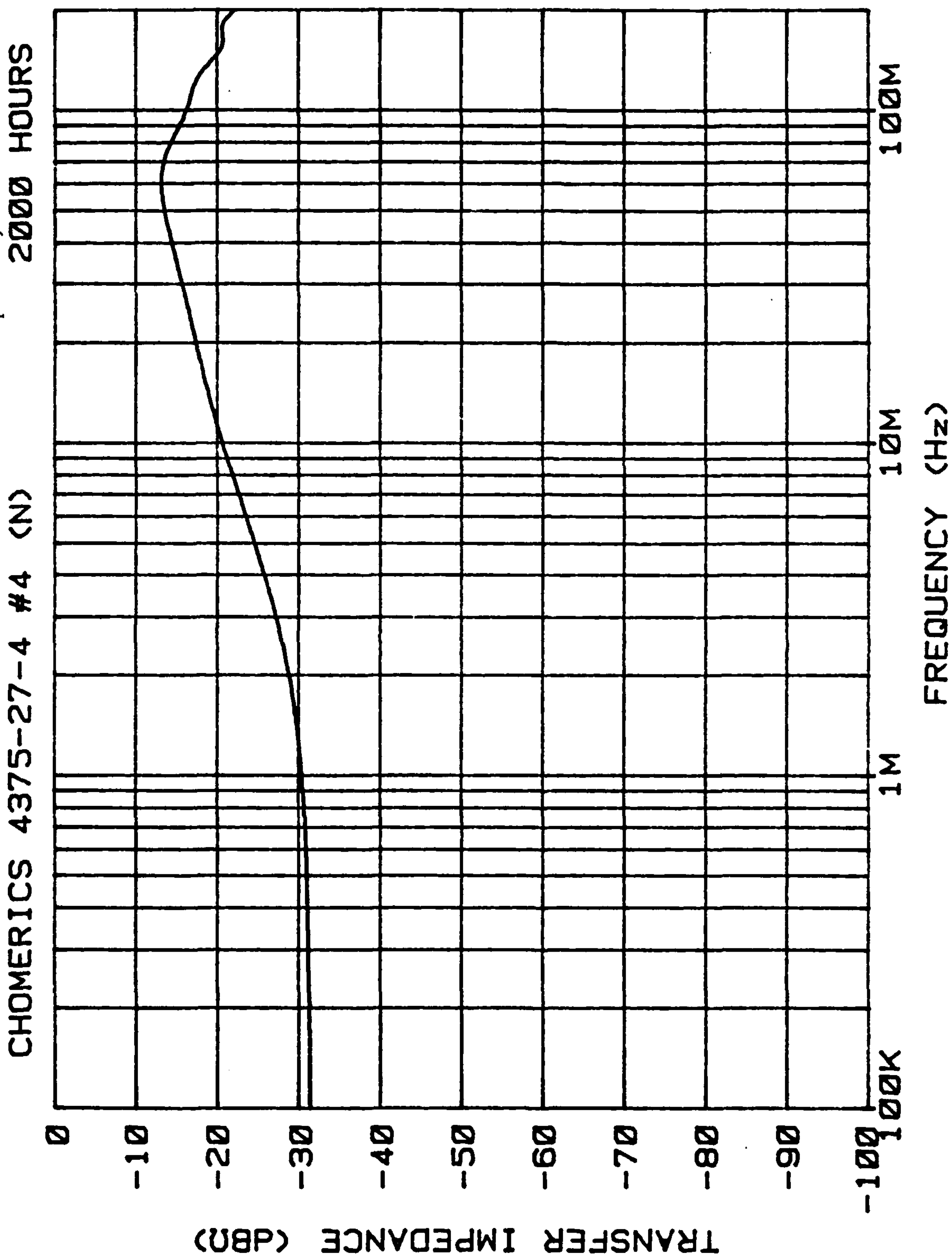
Test Sample A2, 2000 Hrs.



Test Sample A3, 2000 Hrs.

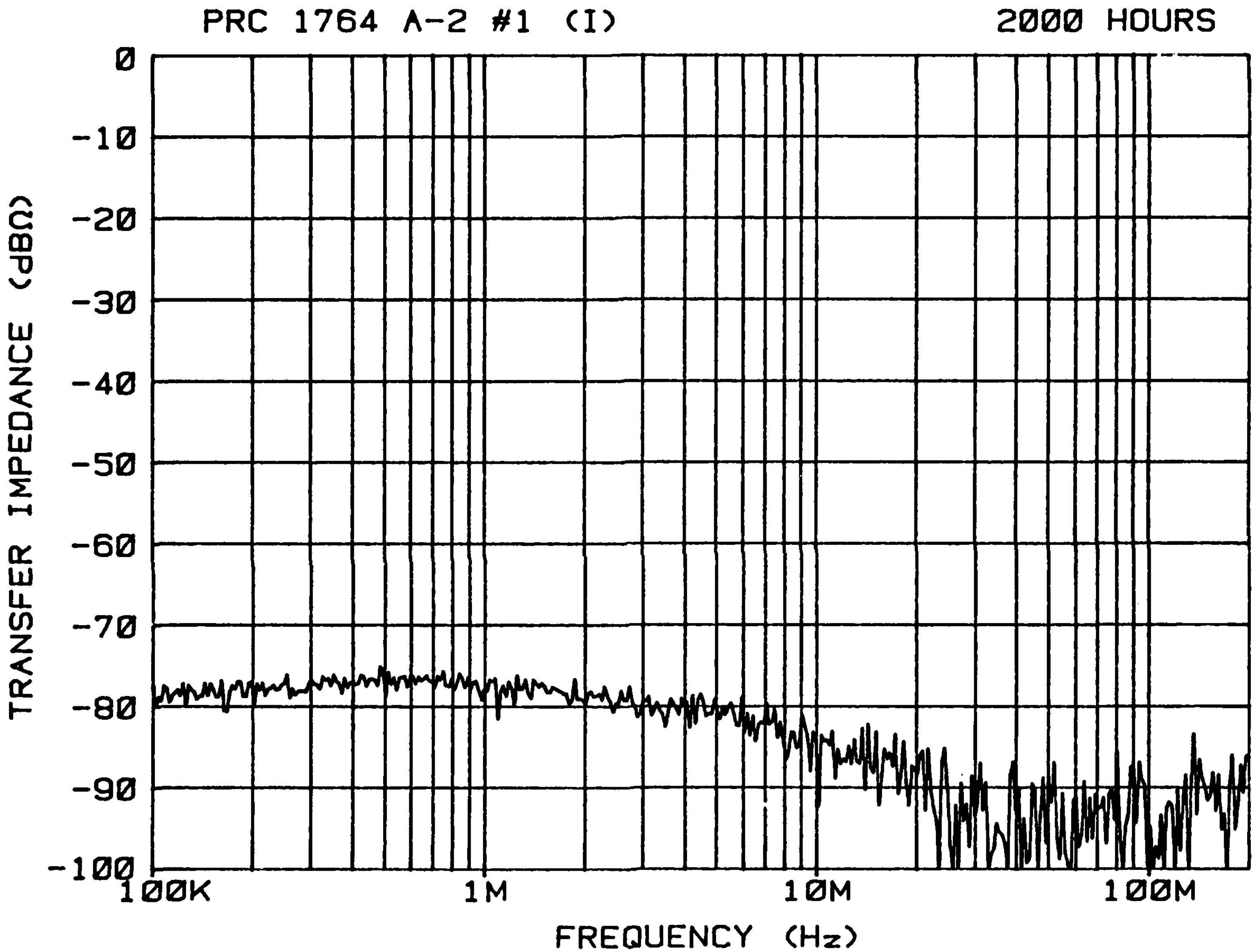
CHOMERICS 4375-27-4 #3 (I) 2000 HOURS



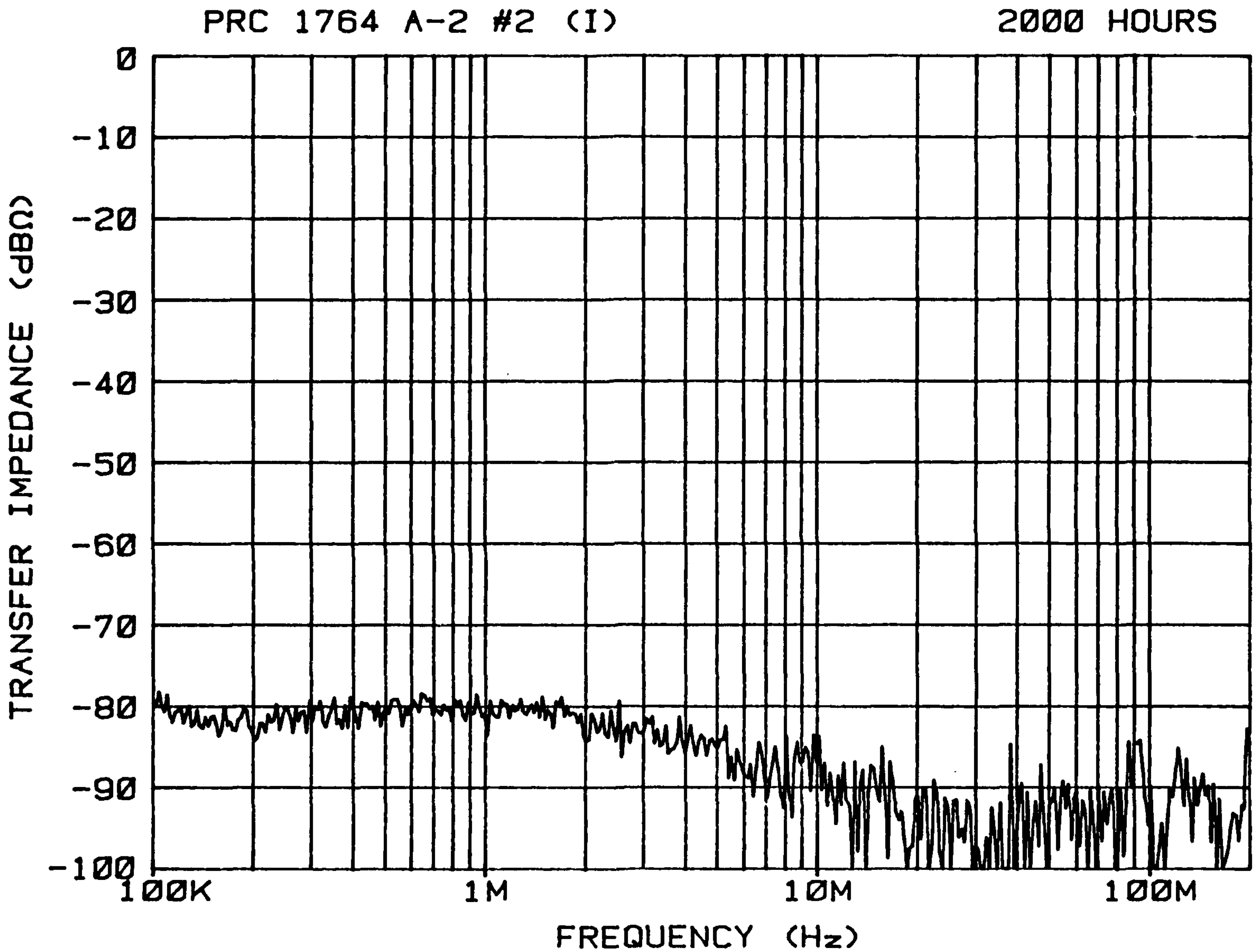


Test Sample A4, 2000 Hrs.

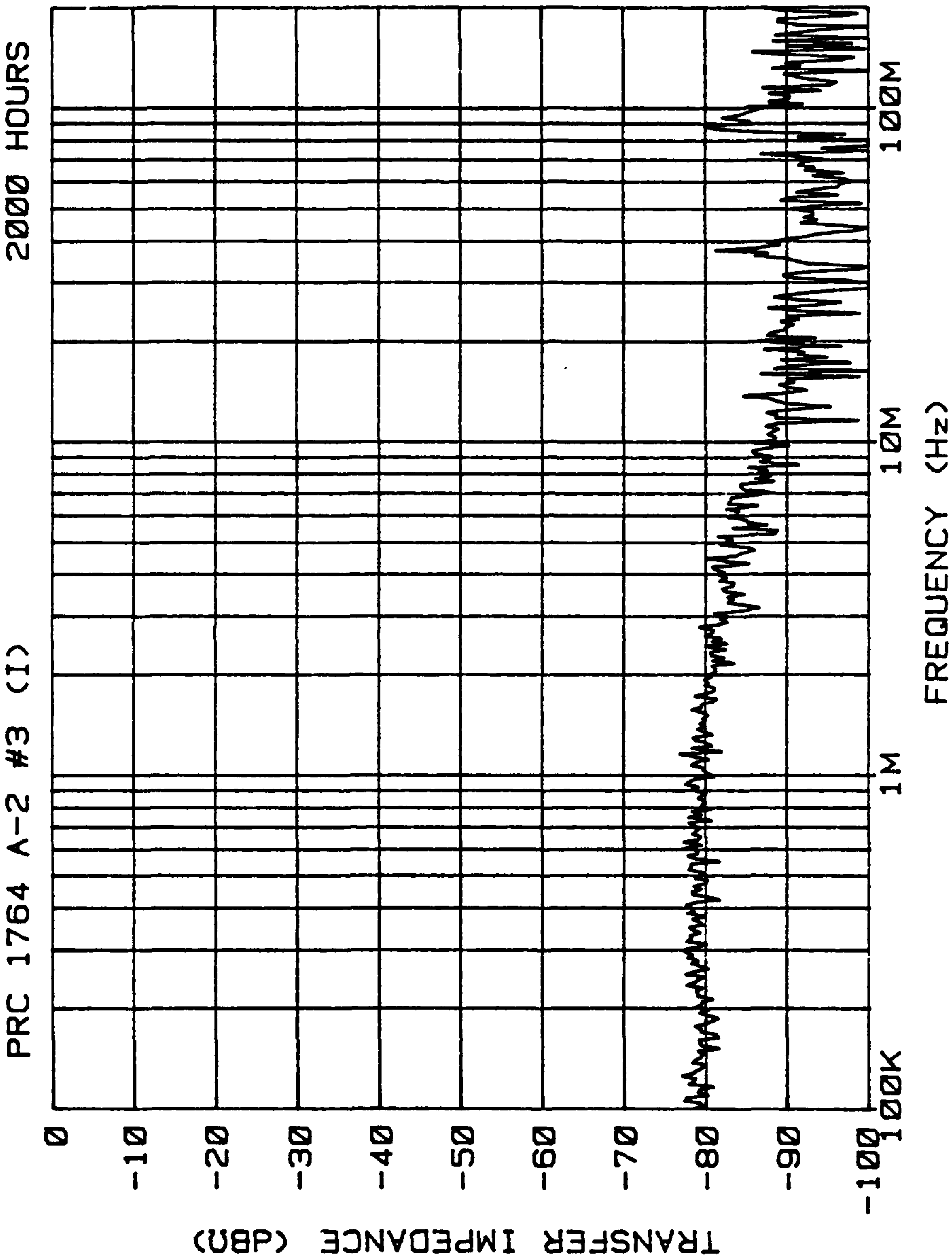
Test Sample C1, 2000 Hrs.

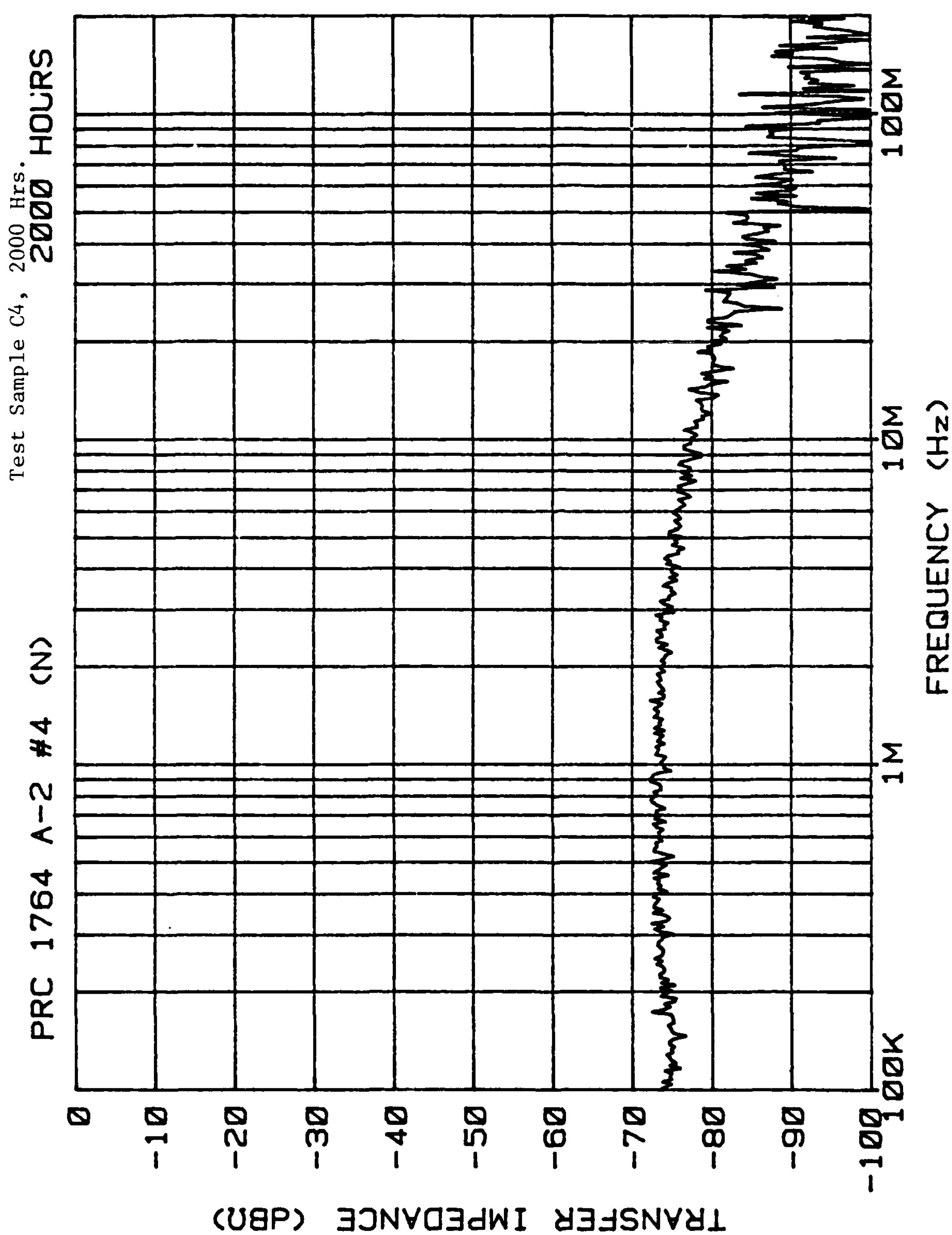


Test Sample C2, 2000 Hrs.



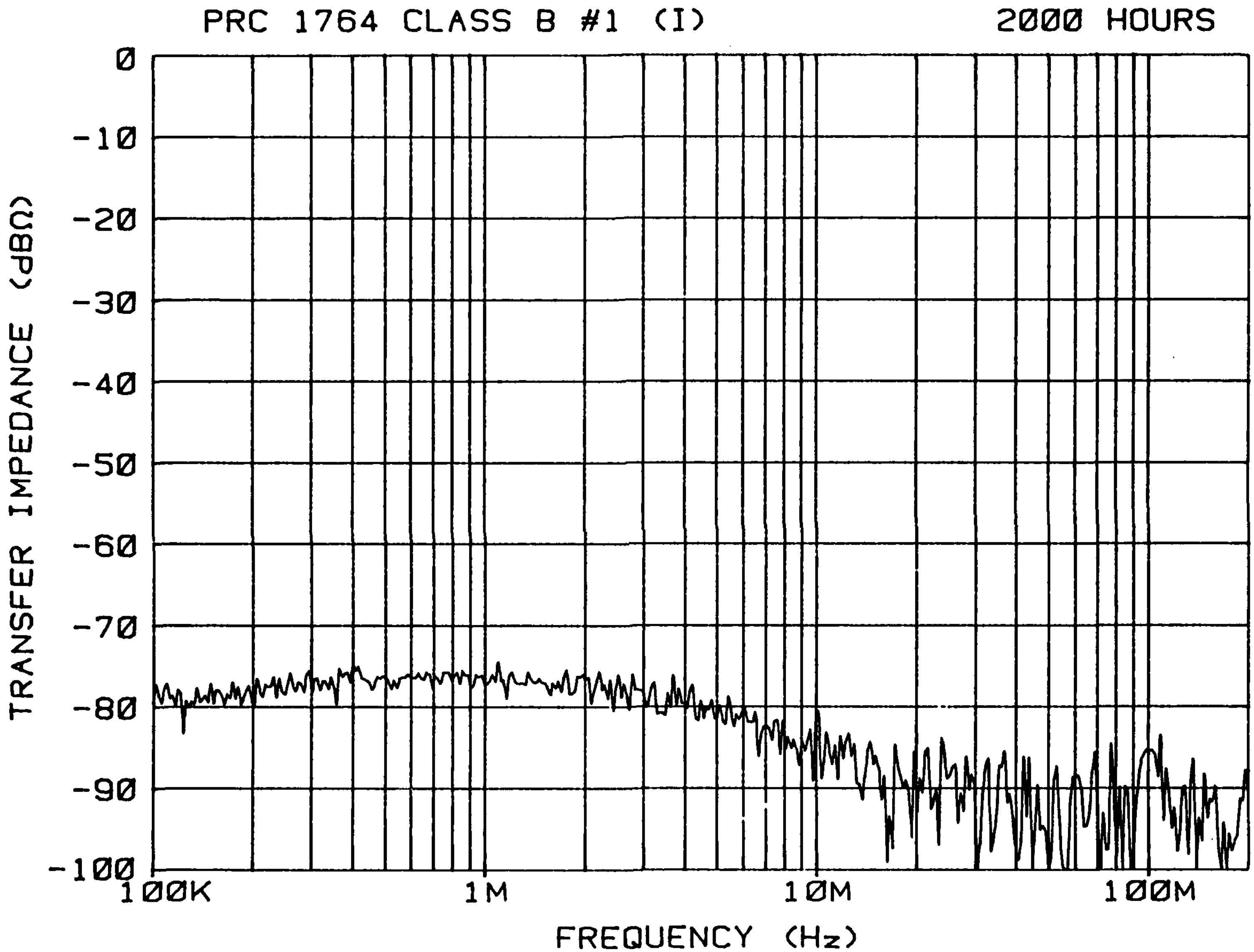
Test Sample C3, 2000 Hrs.



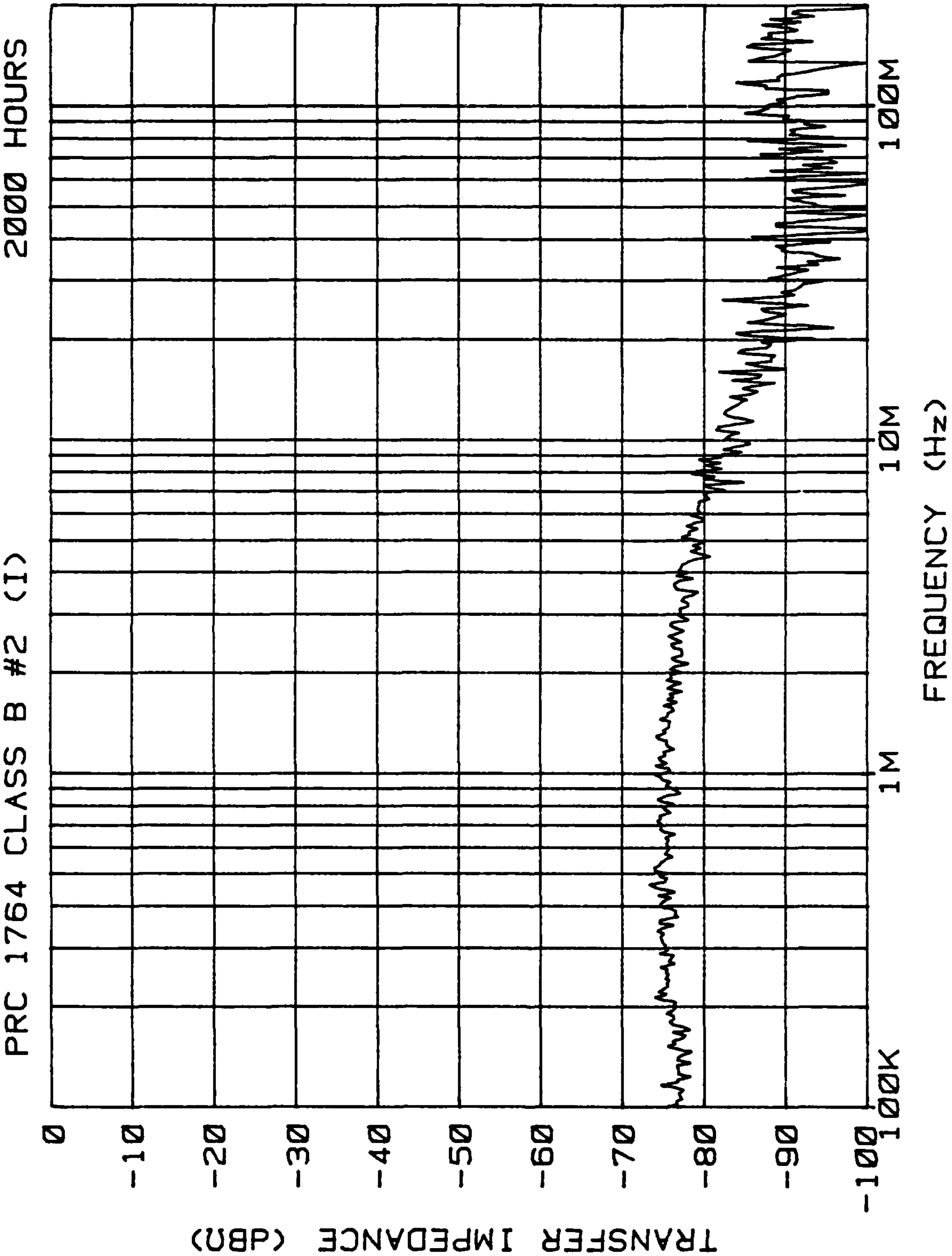


Test Sample C4, 2000 Hrs.
PRC 1764 A-2 #4 (N)
2000 HOURS
TRANSFER IMPEDANCE (dBΩ)
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
100K
1M
10M
100M
FREQUENCY (Hz)

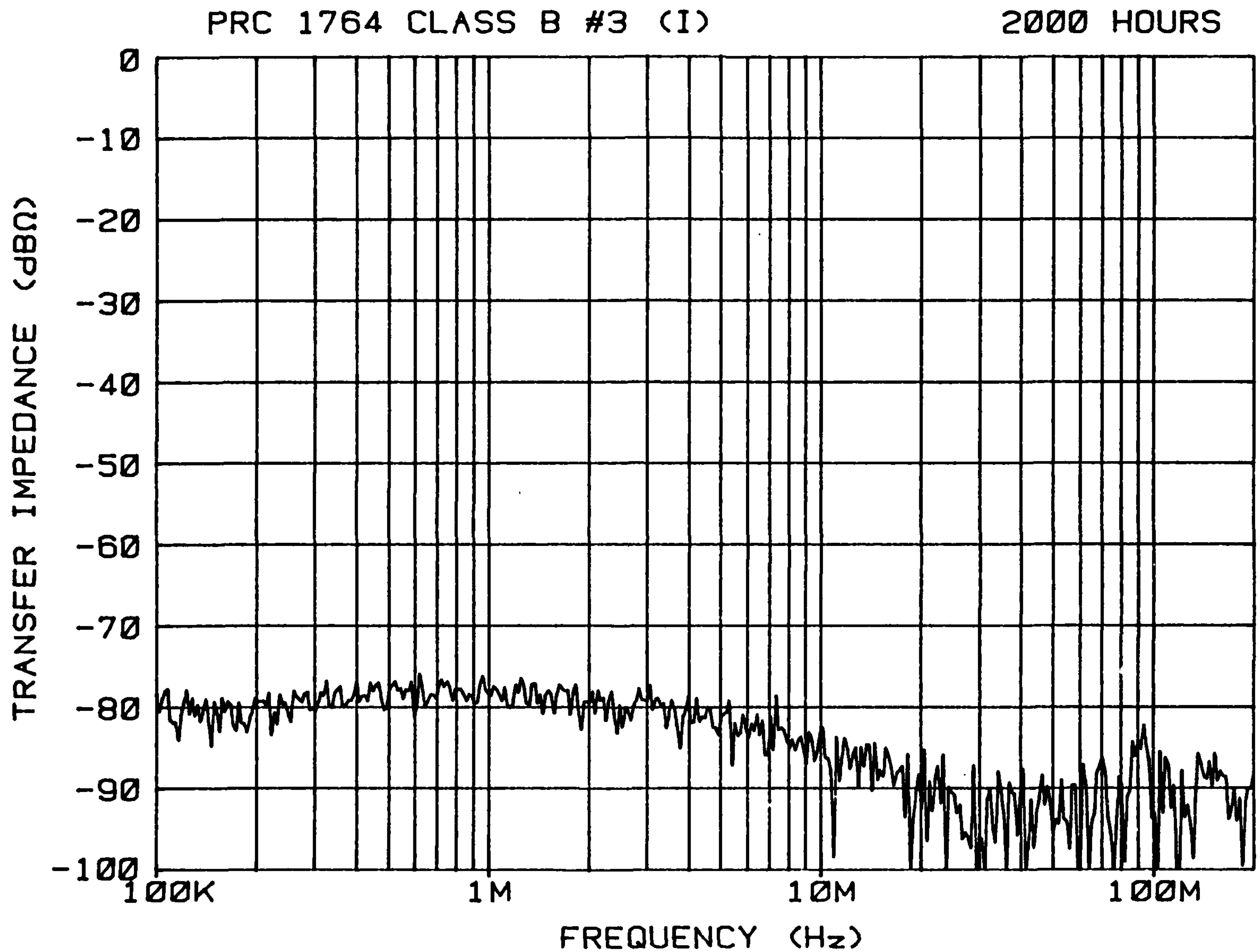
Test Sample D1, 2000 Hrs.

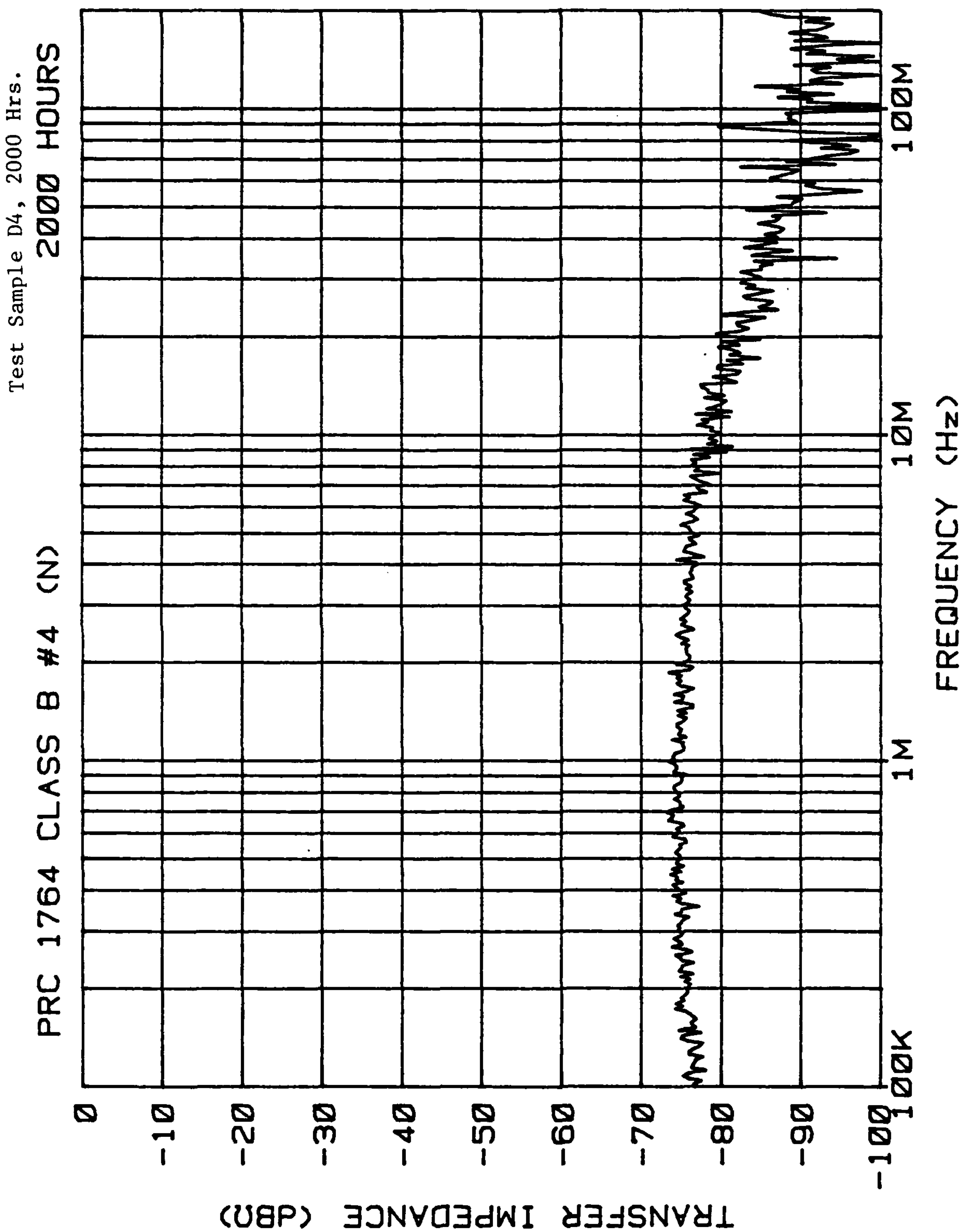


Test Sample D2, 2000 Hrs.



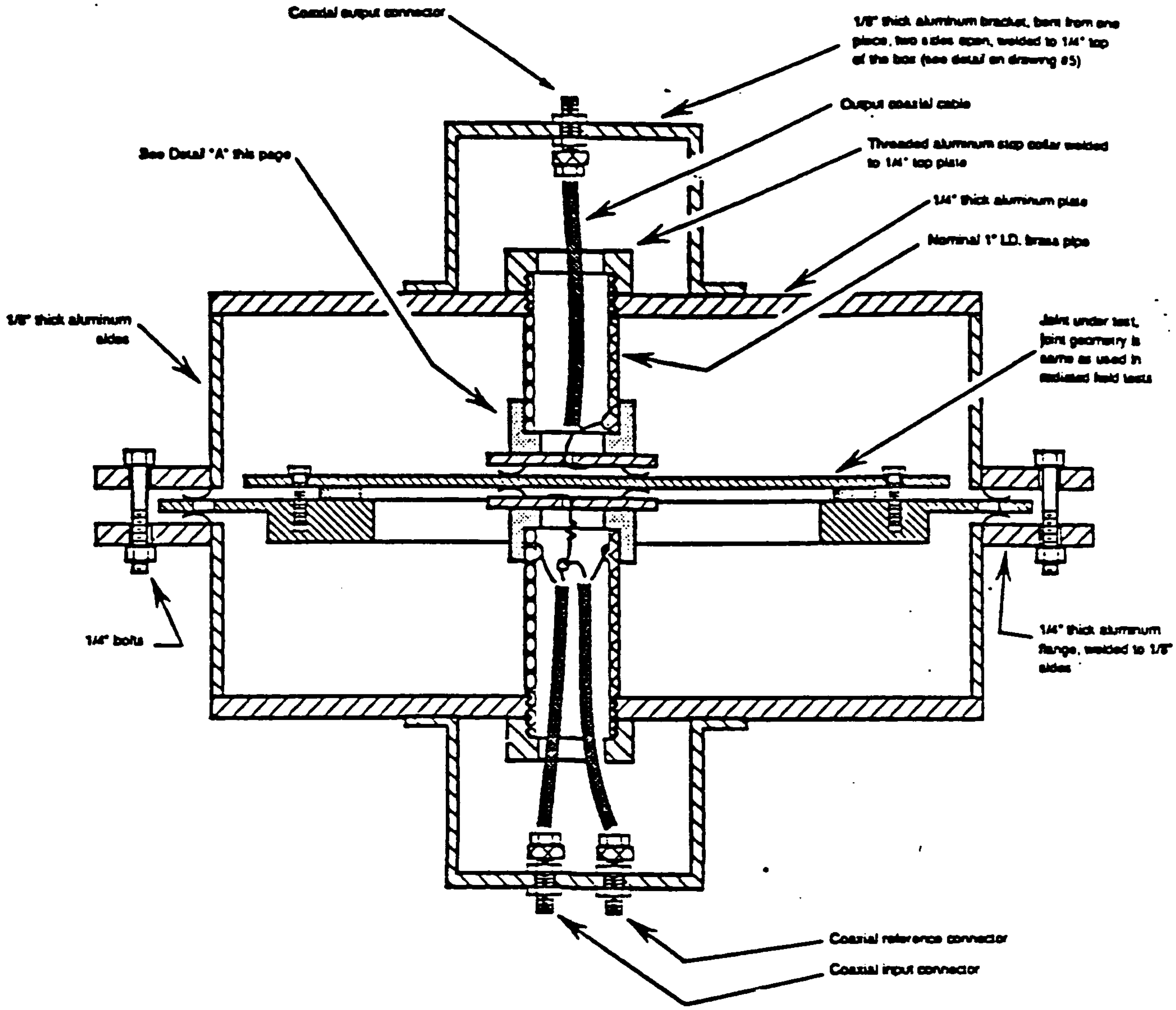
Test Sample D3, 2000 Hrs.



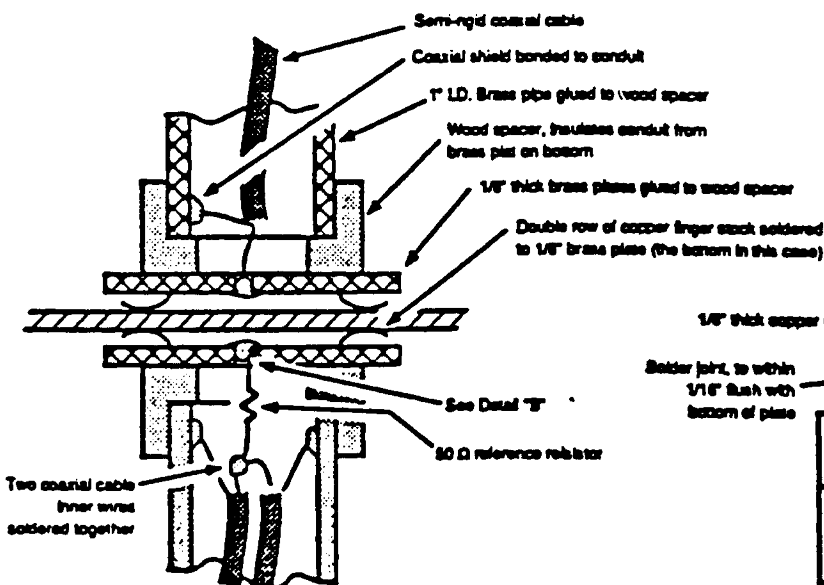

Test Sample D4, 2000 Hrs.
PRC 1764 CLASS B #4 (N)
2000 HOURS
TRANSFER IMPEDANCE (dBΩ)
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
100K
1M
10M
100M
FREQUENCY (Hz)

APPENDIX C

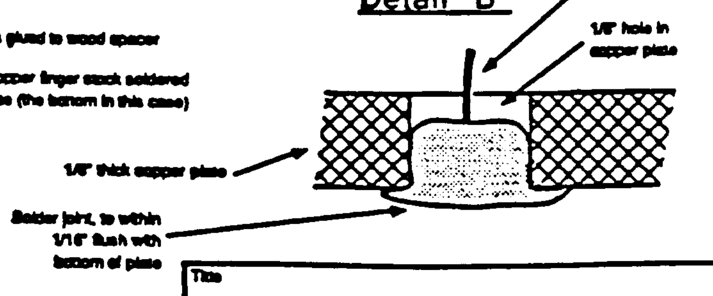
DRAWINGS FOR TRANSFER IMPEDANCE TEST FIXTURE



Detail "A"



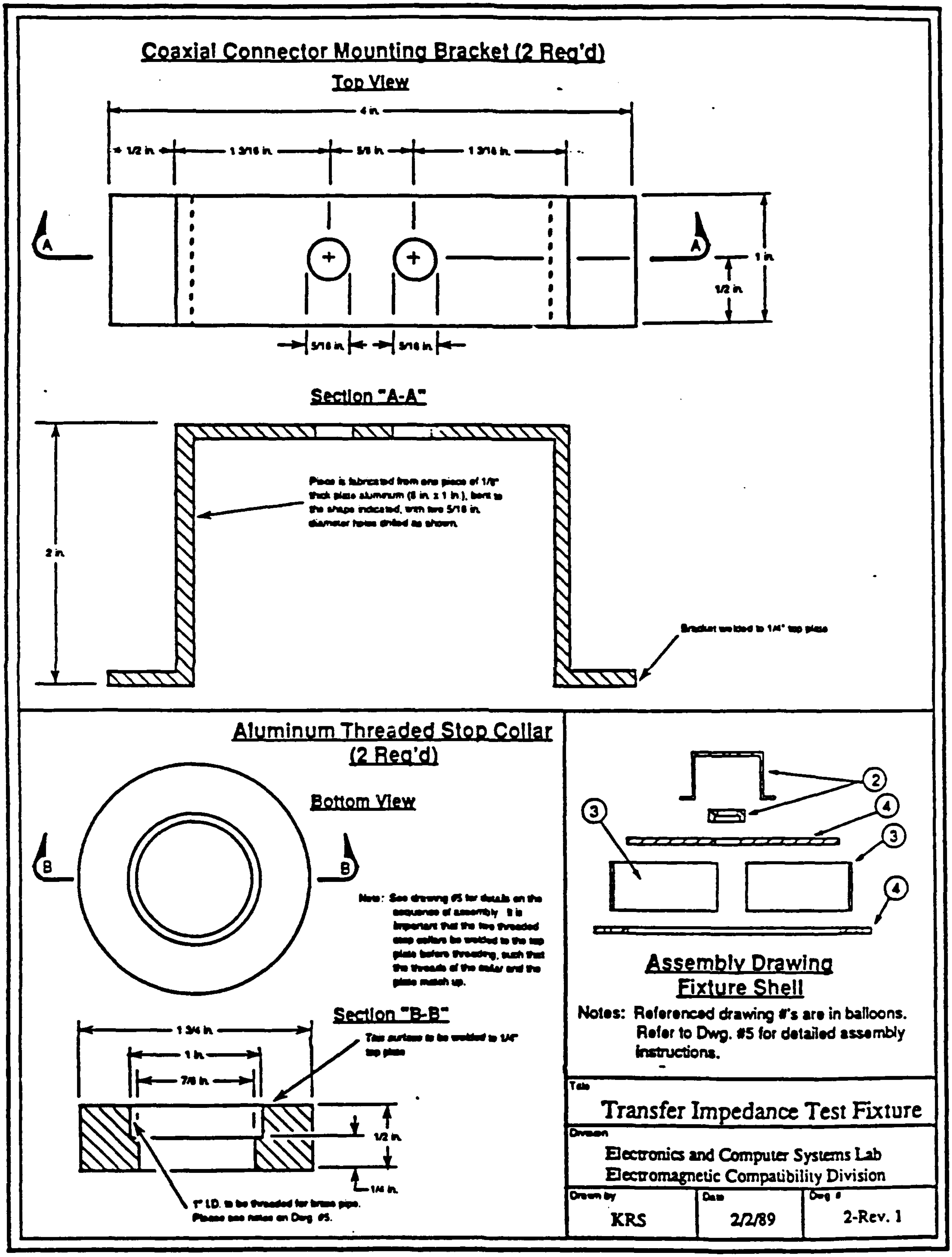
Detail "B"

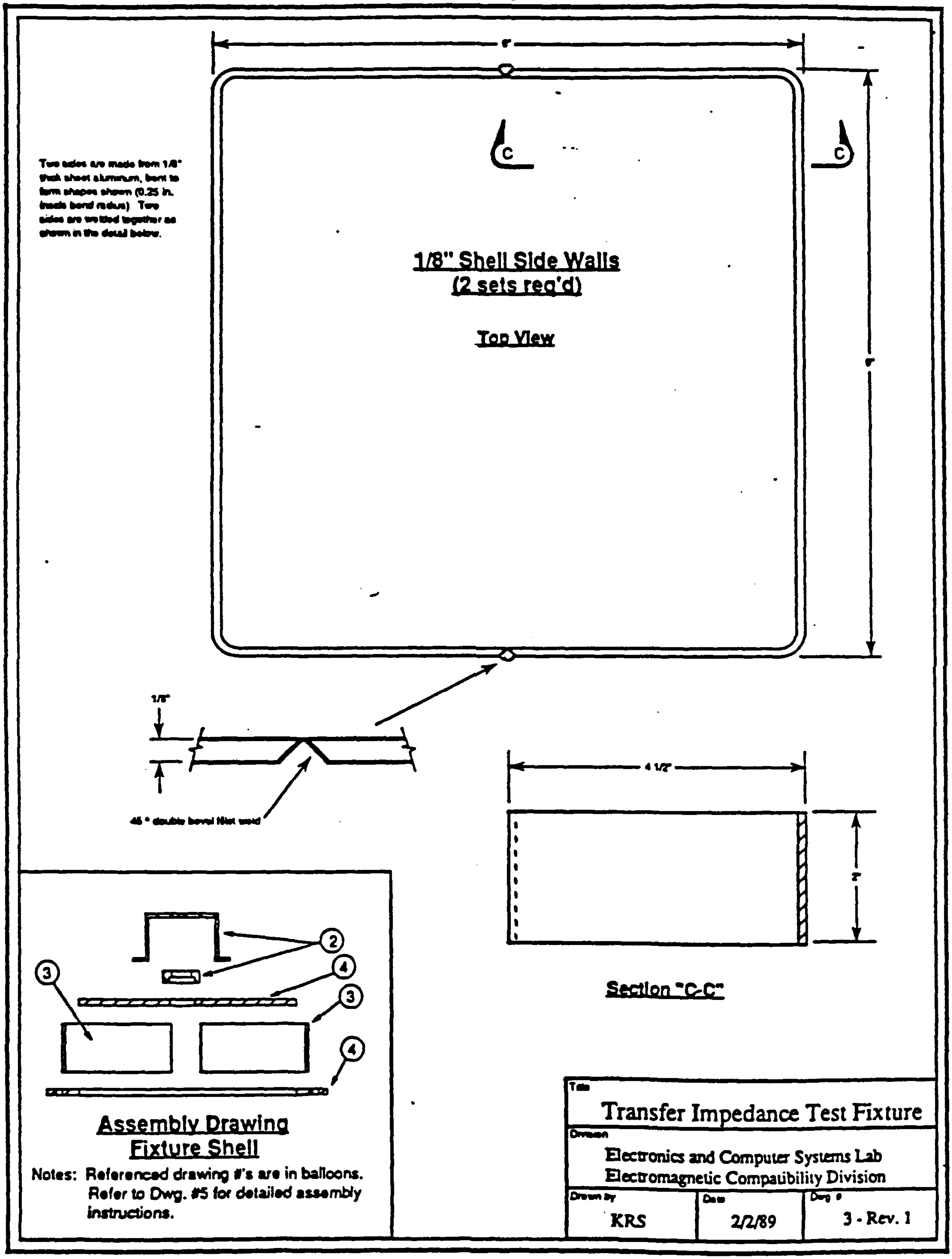


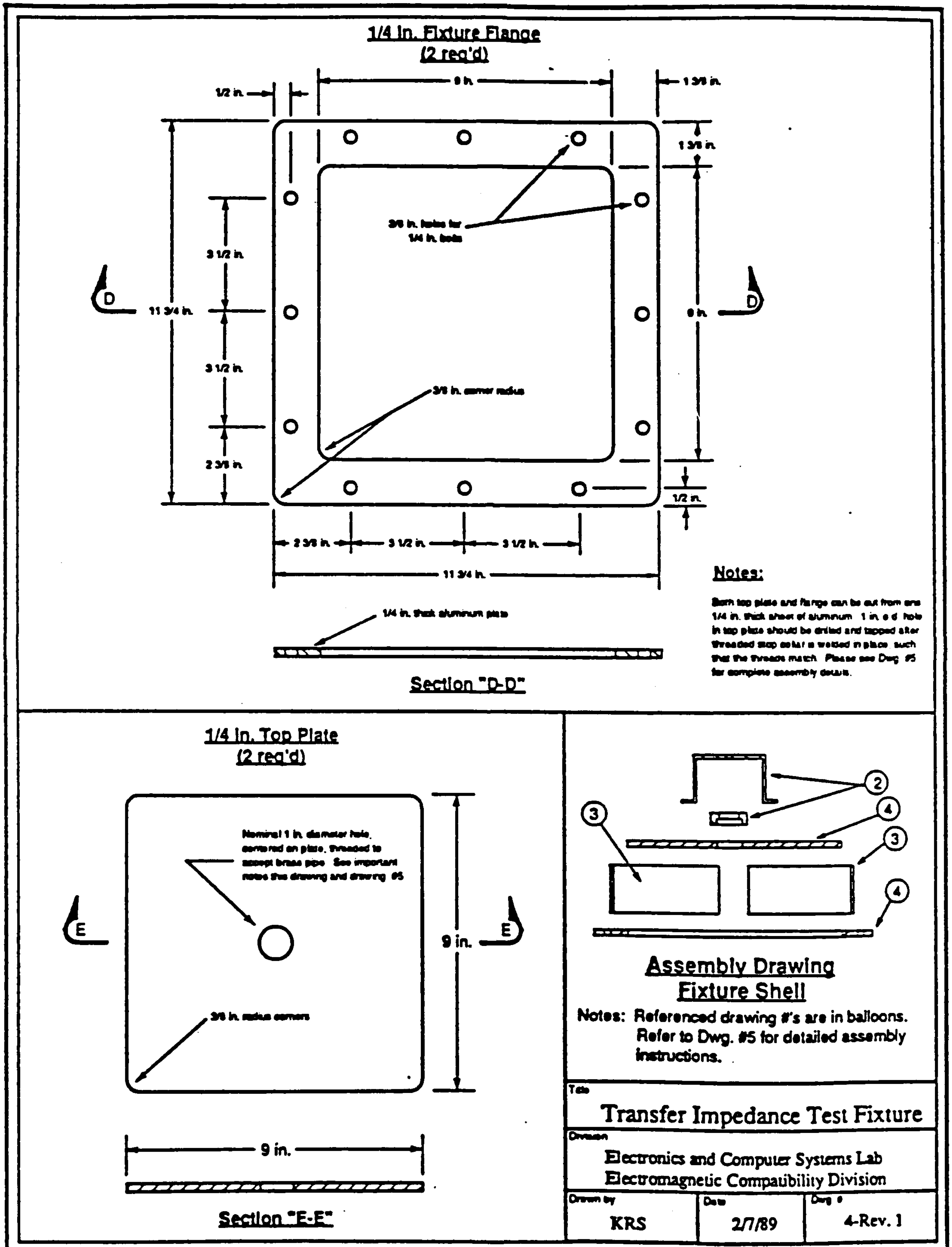
Title: Transfer Impedance Test Fixture

Division: Electronics and Computer Systems Lab
Electromagnetic Compatibility Division

Drawn by	Date	Dwg. #
KRS	1/31/89	1-Rev. 2


Coaxial Connector Mounting Bracket (2 Req'd)
Top View
4 in.
1/2 in.
1 3/16 in.
5/8 in.
1 3/16 in.
A
A
1 in.
1/2 in.
5/16 in.
5/16 in.
Section "A-A"
2 in.
Aluminum Threaded Stop Collar
(2 Req'd)
Bottom View
B
B
Section "B-B"
1 3/4 in.
1 in.
7/8 in.
1/2 in.
1/4 in.
2
4
3
3
4
Assembly Drawing
Fixture Shell
Notes: Referenced drawing #'s are in balloons.
Refer to Dwg. #5 for detailed assembly instructions.
Transfer Impedance Test Fixture
Electronics and Computer Systems Lab
Electromagnetic Compatibility Division
KRS
2/2/89
2-Rev. 1


Two sides are made from 1/8" thick sheet aluminum, bent to form shapes shown (0.25 in. inside bend radius). Two sides are welded together as shown in the detail below.
9"
9"
C
C
1/8" Shell Side Walls
(2 sets req'd)
Top View
1/8"
45 ° double bevel fillet weld
4 1/2"
2"
Section "C-C"
2
3
4
3
4
Assembly Drawing
Fixture Shell
Notes: Referenced drawing #'s are in balloons.
Refer to Dwg. #5 for detailed assembly instructions.
Title
Transfer Impedance Test Fixture
Division
Electronics and Computer Systems Lab
Electromagnetic Compatibility Division
Drawn by
KRS
Date
2/2/89
Dwg #
3 - Rev. 1


1/4 In. Fixture Flange
(2 req'd)
1/2 in.
9 in.
1 3/8 in.
3/8 in. holes for 1/4 in. bolts
3 1/2 in.
11 3/4 in.
3 1/2 in.
9 in.
3/8 in. corner radius
2 3/8 in.
1/2 in.
2 3/8 in.
3 1/2 in.
3 1/2 in.
11 3/4 in.
D
D
1/4 in. thick aluminum plate
Section "D-D"
Notes:
Both top plate and flange can be cut from one 1/4 in. thick sheet of aluminum. 1 in. o.d. hole in top plate should be drilled and tapped after threaded stop collar is welded in place, such that the threads match. Please see Dwg. #5 for complete assembly details.
1/4 In. Top Plate
(2 req'd)
Nominal 1 in. diameter hole, centered on plate, threaded to accept brass pipe. See important notes this drawing and drawing #5
3/8 in. radius corners
9 in.
E
E
9 in.
Section "E-E"
2
3
4
3
4
Assembly Drawing
Fixture Shell
Notes: Referenced drawing #'s are in balloons.
Refer to Dwg. #5 for detailed assembly instructions.
Title
Transfer Impedance Test Fixture
Division
Electronics and Computer Systems Lab
Electromagnetic Compatibility Division
Drawn by
KRS
Date
2/7/89
Dwg #
4-Rev. 1

General Notes and Assembly Steps

General Notes:

1. The inside and outside diameter dimensions shown for the brass pipe are suggested only. If standard sizes are available, the one that most closely matches the dimensions shown. If a size with dimensions other than those shown is selected, it is necessary to modify the other parts which mate to the brass pipe such that they mate correctly with it. Specifically, the hole cut into the 1/4" thick top aluminum plate must be modified to reflect the new O.D. dimension of the pipe. (The hole should not be cut to the O.D. dimension. Rather, the hole should be cut to facilitate the tapping to mate with the threads of the pipe). Also, the aluminum threaded stop collar hole I.D. dimension must be modified (in the same fashion as the 1/4" plate hole). Finally, the large I.D. of the wood spacer must be modified to match the O.D. of the brass pipe (this part has no thread). Note that the minimum I.D. of the brass pipe must be 7/8".

2. Both the top and flange 1/4" aluminum plates can be cut from the same sheet (because the cutout of the flange is precisely the same size as the top plate). If it is convenient to cut the flange piece in two, and then weld it back together to accomplish the cut out, then this is acceptable.

3. The threading of the stop collar and the hole in the 1/4" top plate should not be done until the stop collar is welded to the top plate. This is necessary because these threads must match up so that the brass pipe can be screwed into the resulting threaded hole.

4. Do not glue brass pipe, wood spacer, and brass contact plates together. The wiring shown on drawing #1 must be installed first. This will be done by EMCD personnel.

Assembly Steps:

1. Fabricate the aluminum 1/4" top plates (2 req'd) and 1/4" flanges (2 req'd). Cut flange pieces into two pieces if necessary, and if done, weld back together (insuring that mating surfaces are flush). Drill flange holes, and drill brass pipe hole in top plates. Do not tap pipe holes yet.

2. Fabricate the aluminum stop collars, as shown on the drawings, but do not tap larger inside diameter yet.

3. Weld stop collars to top plates, centering brass pipe holes.

4. Thread top plate and stop collars simultaneously. See general notes above for important notes on this step.

5. Fabricate side walls from 1/8" thick aluminum plate. Weld sides to [illegible]ar as shown on drawing. Note that once welding is complete, will have two side pieces (one for the top shell and one for the bottom shell).

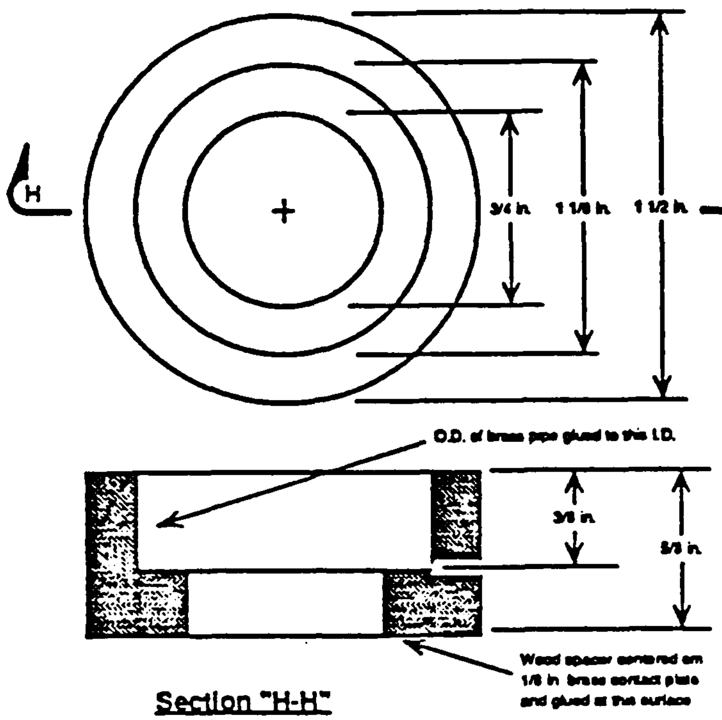
6. Fabricate coaxial connector brackets from 1/8" thick aluminum plate.

7. Weld flange pieces to side wall pieces, weld 1/4" thick top plates to side walls, and weld coaxial connector brackets to top 1/4" plates.

8. Cut to length four brass pipes, thread to match top plate/stop collar threaded holes. Fabricate four wooden spacers and brass contact plates. Do not glue these pieces together. (Wiring must be connected first. This will be done by EMCD personnel.)

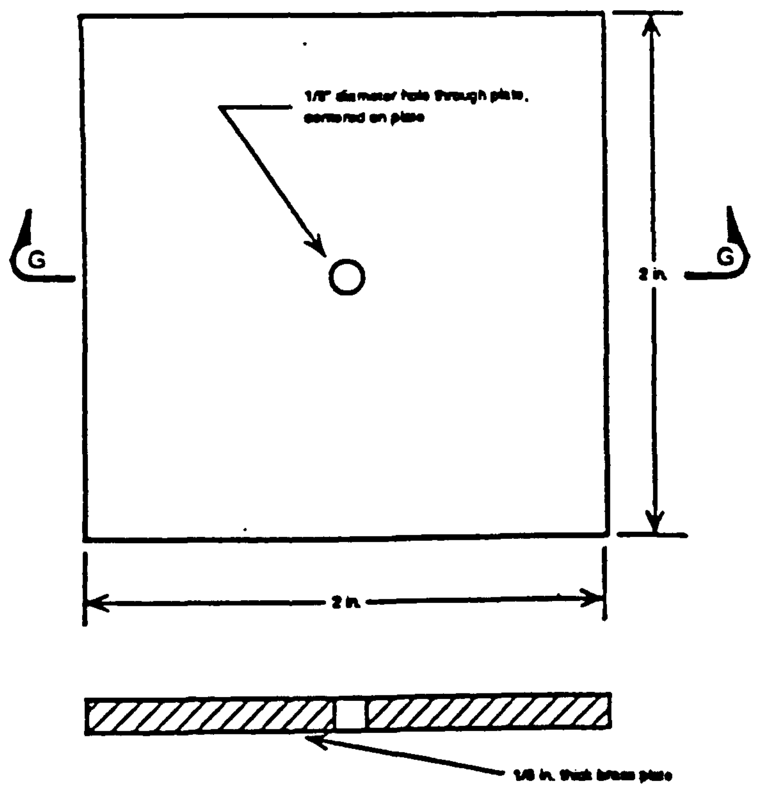
Title		
Transfer Impedance Test Fixture		
Division		
Electronics and Computer Systems Lab Electromagnetic Compatibility Division		
Drawn by	Date	Dwg. #
KRS	2/7/89	5

Wood Spacer
(4 req'd)



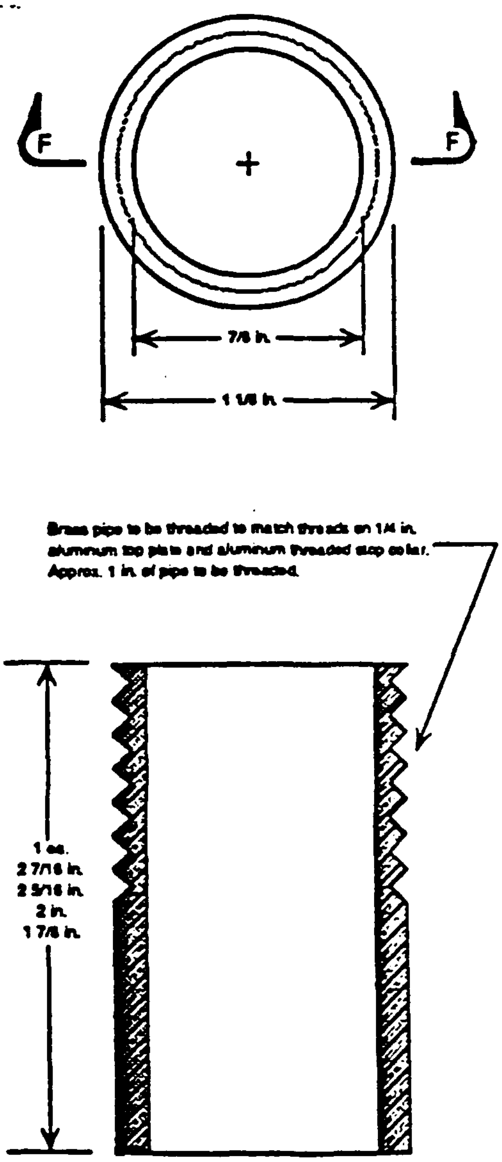
Section "H-H"

1/8 in. Brass Contact Plate
(4 req'd)



Section "G-G"

Threaded Brass Pipe
(4 req'd, all different lengths)



Section "F-F"

NOTES: Inside and outside dimensions for the brass pipe are approximate. Standard pipe sizes (if available) matching the above diameter dimensions as closely as possible should be used. Note that if pipe of different diameter dimensions is used, then hole in 1/4 in. aluminum top plate, aluminum threaded stop collar, and large I.D. of wood spacer should be changed accordingly. See drawing #5 for full details of changes necessary.

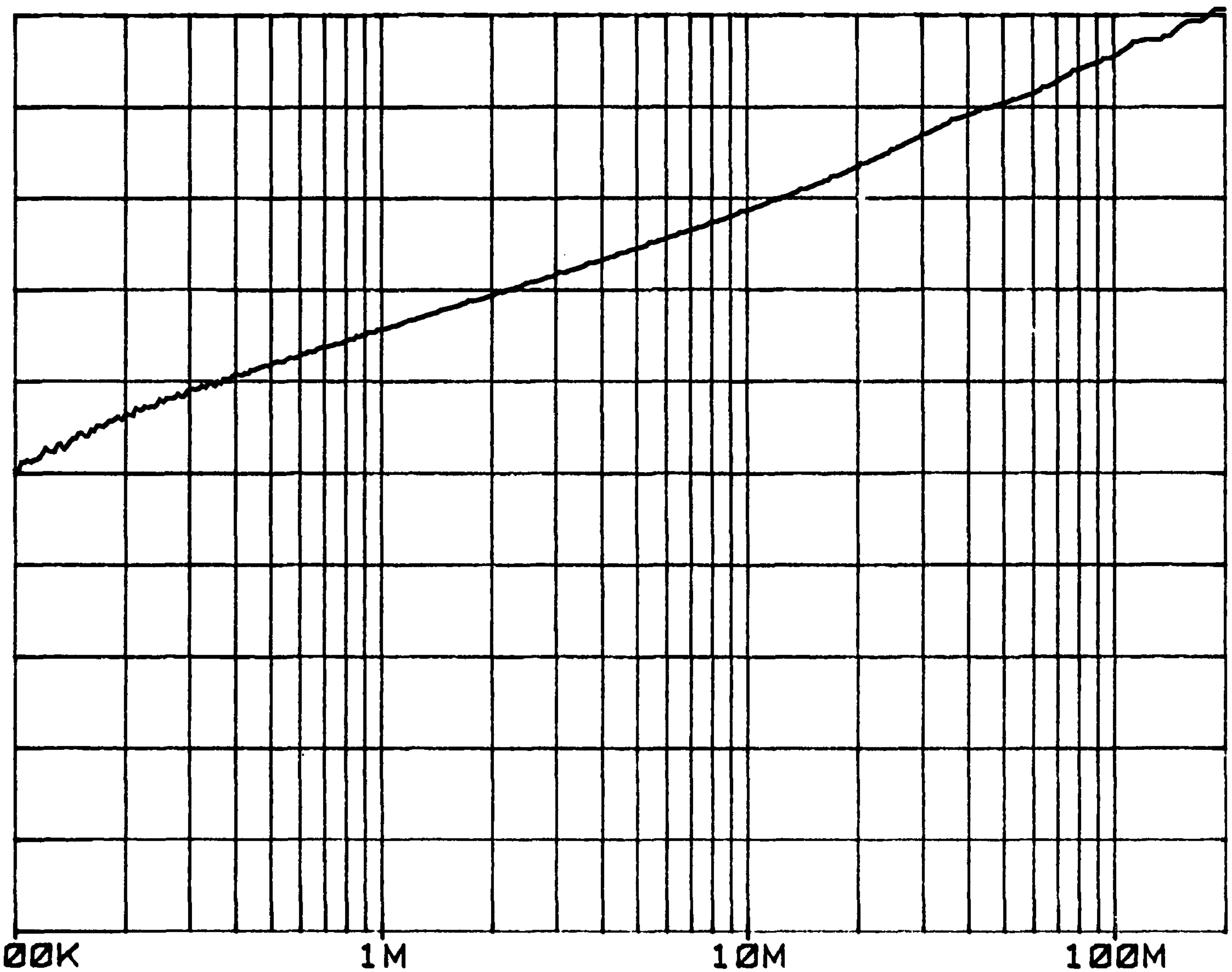
Title: Transfer Impedance Test Fixture		
Division: Electronics and Computer Systems Lab Electromagnetic Compatibility Division		
Drawn by: KRS	Date: 2/7/89	Dwg #: 6

APPENDIX D

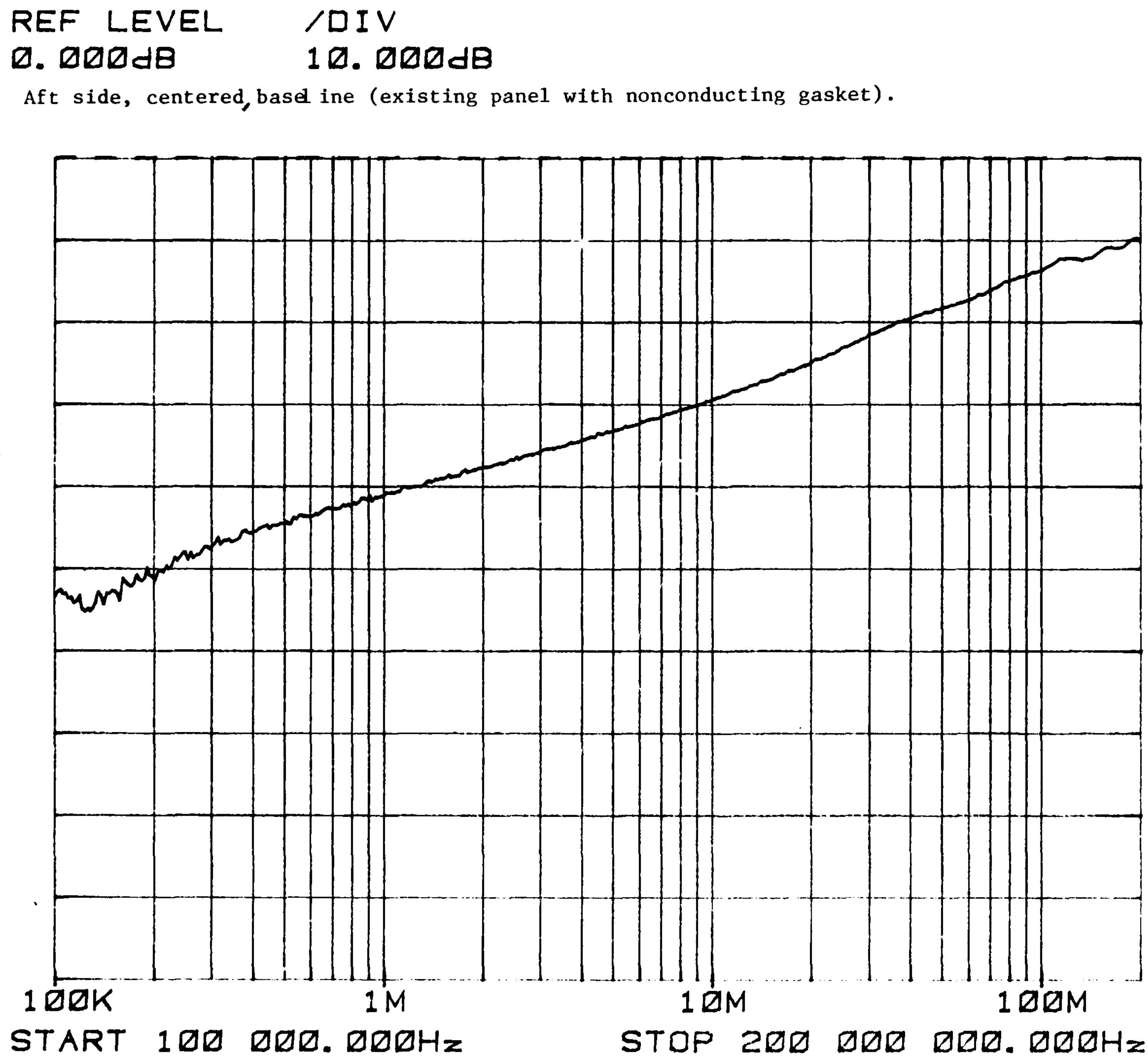
E-3A TAIL PANEL TRANSFER IMPEDANCE DATA

REF LEVEL /DIV
0.000dB 10.000dB

Aft side, 3" from top, baseline (existing panel with nonconducting gasket).



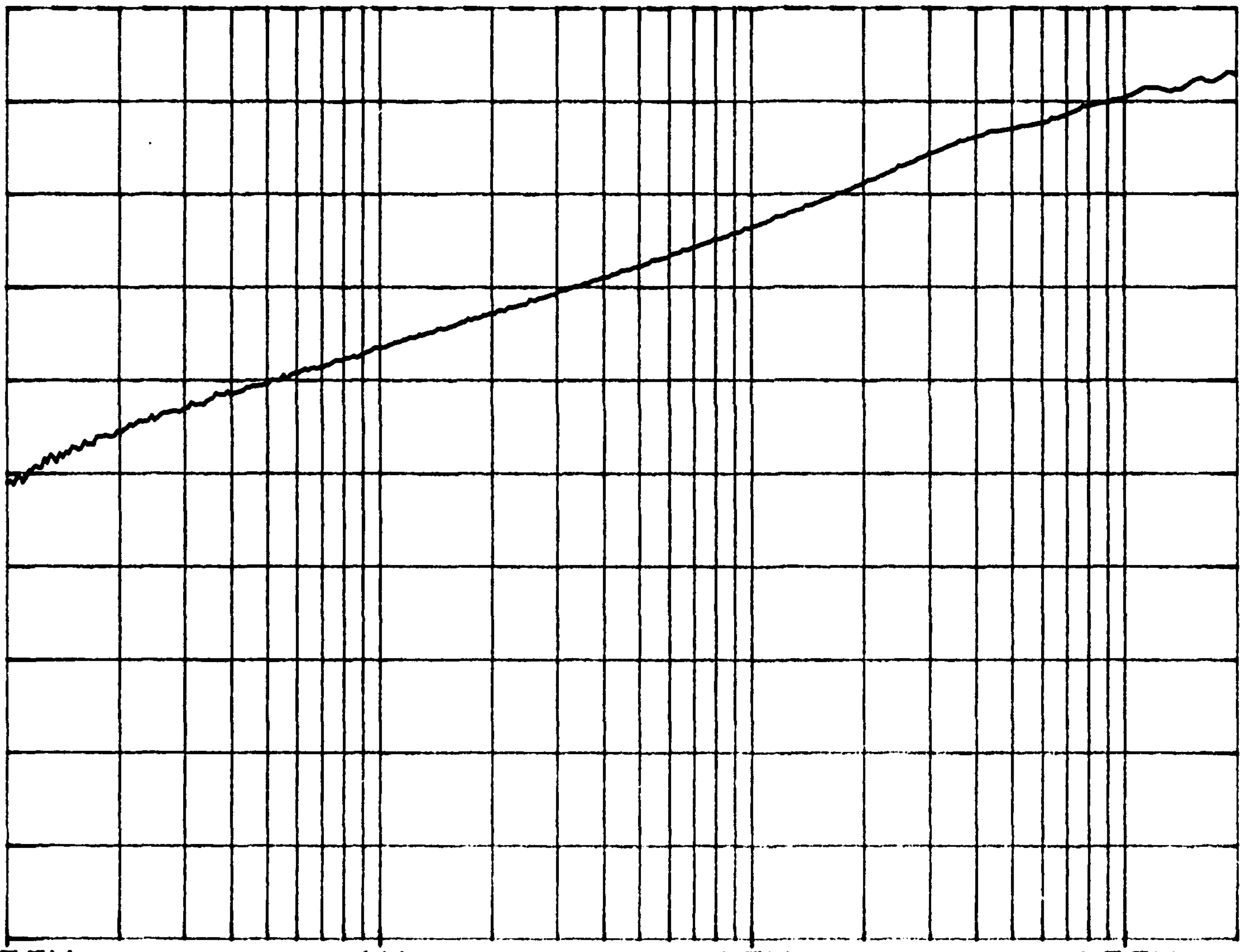
START 100 000.000Hz STOP 200 000 000.000Hz



Aft side, centered, baseline (existing panel with nonconducting gasket).

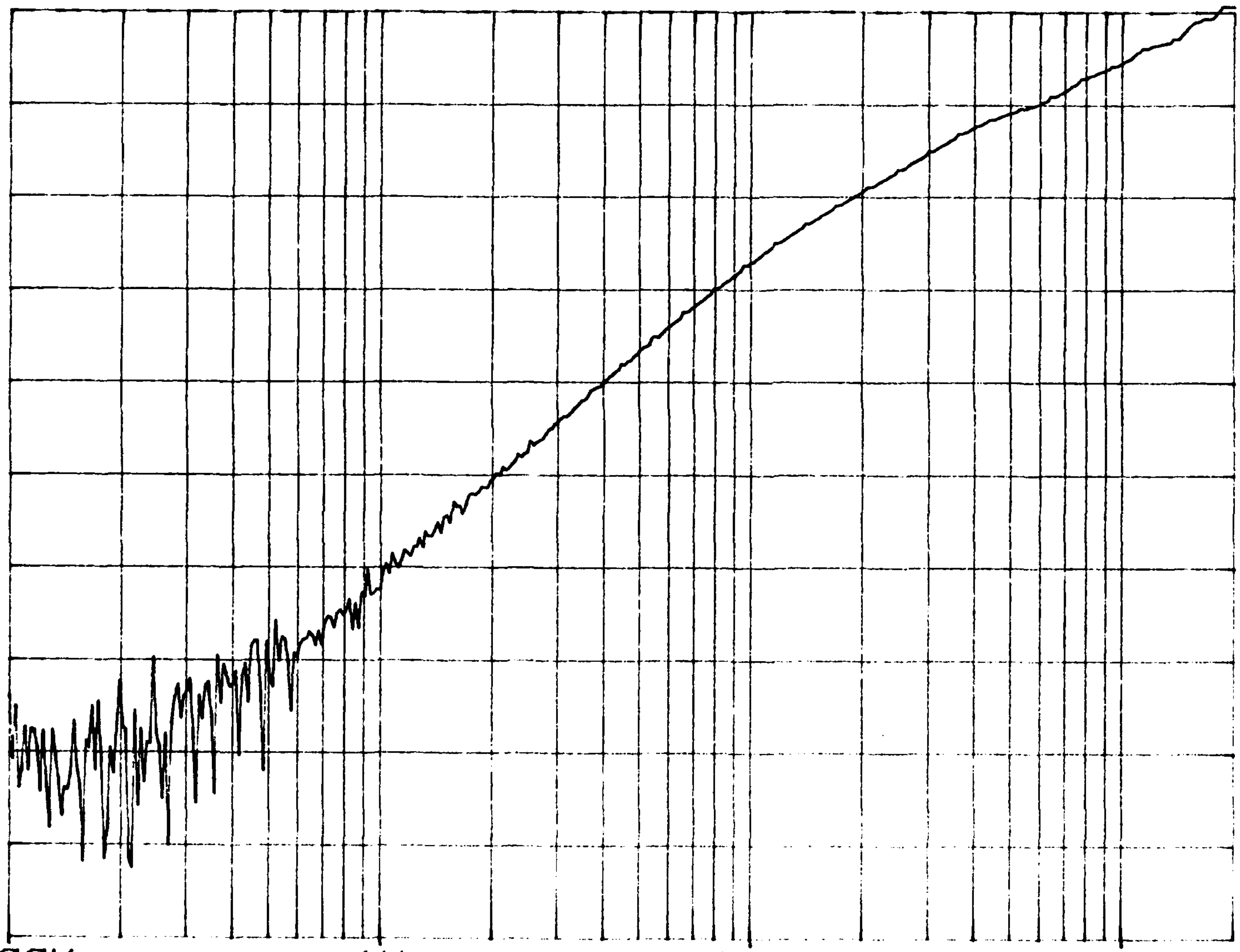
REF LEVEL /DIV
0.000dB 10.000dB

Aft side, 3" from bottom, baseline (existing panel with nonconducting gasket).



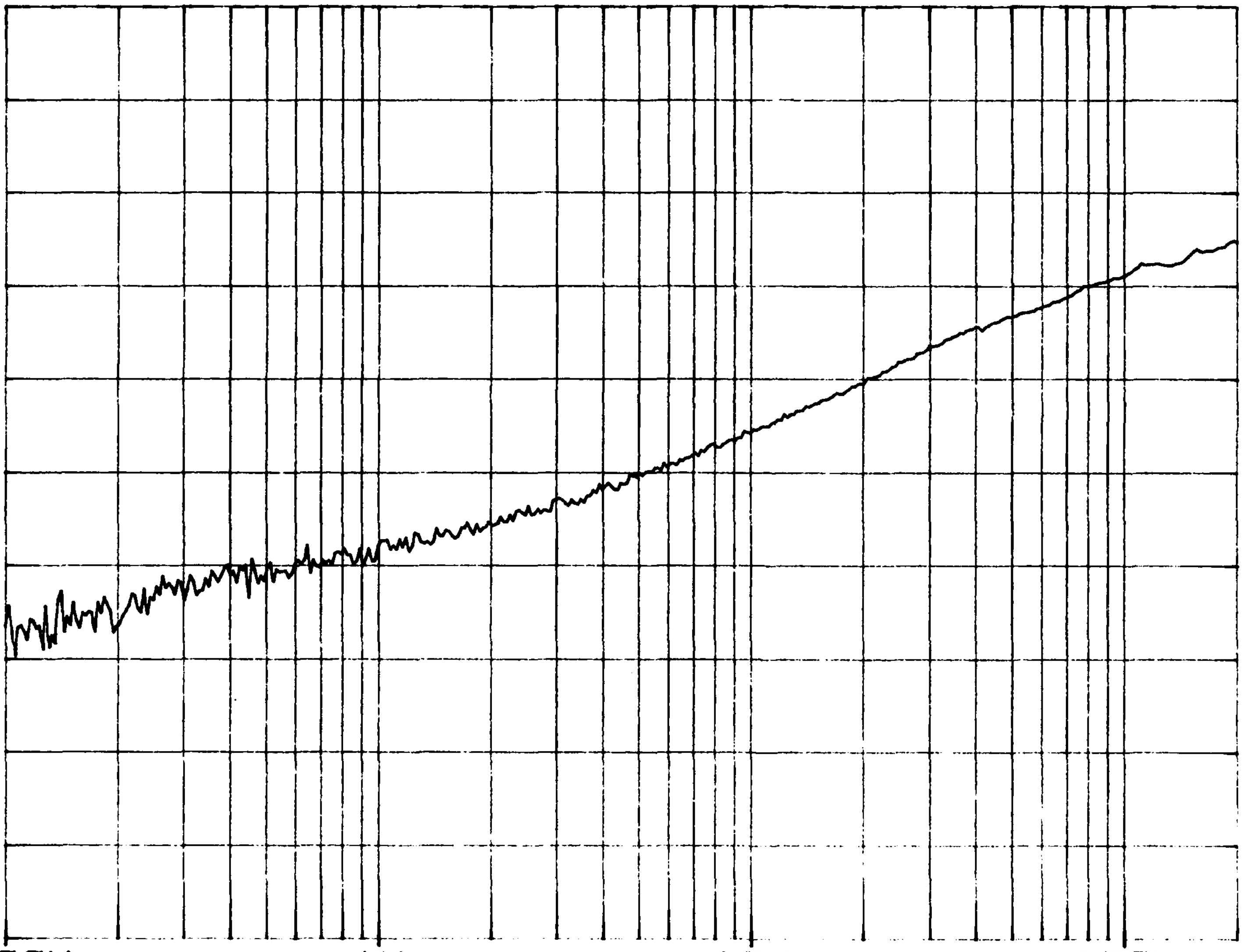
REF LEVEL /DIV
0.000dB 10.000dB

Aft side, 3" from bottom, initial treated (11/29/89).



REF LEVEL /DIV
0.000dB 10.000dB

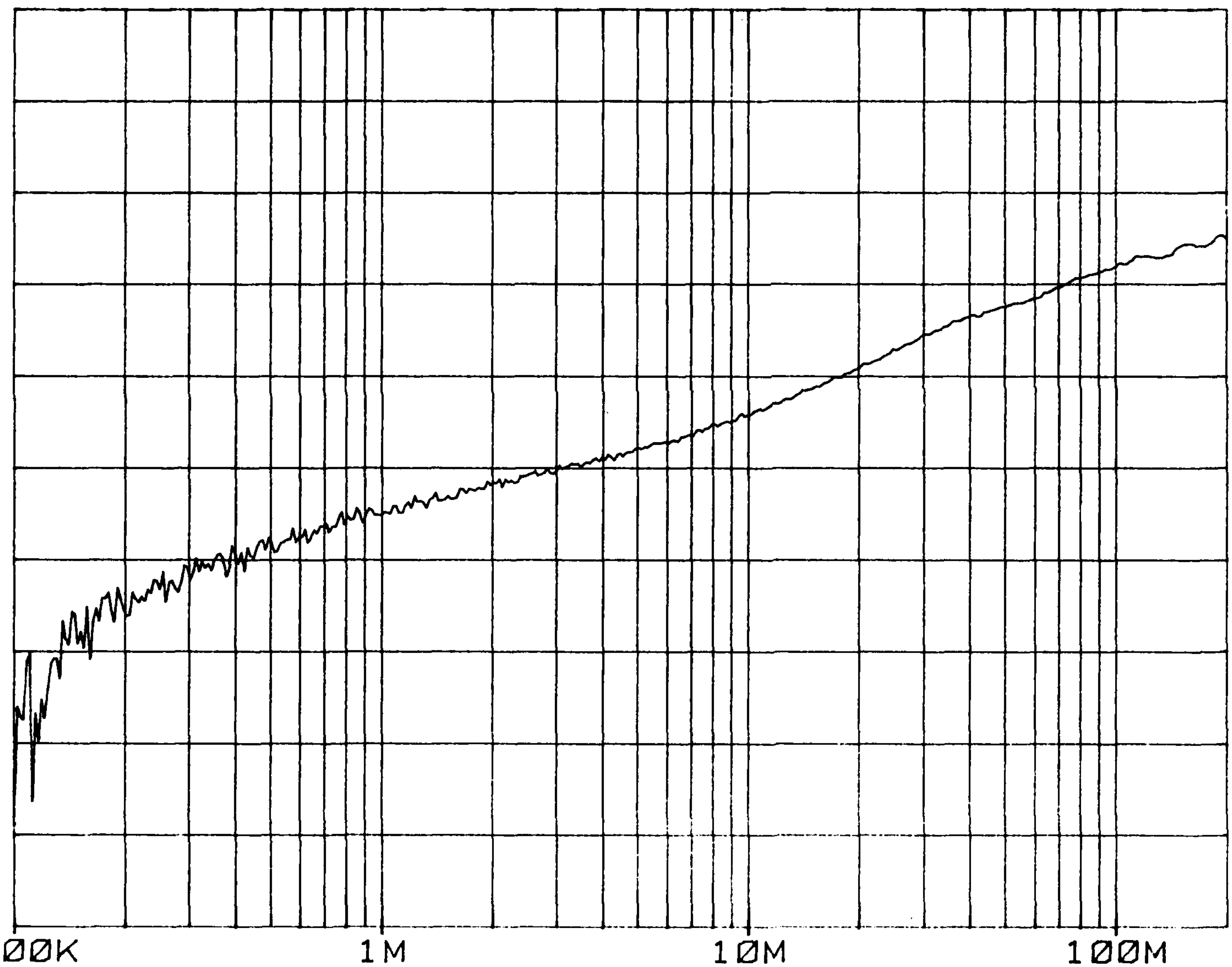
Aft side, centered, initial treated (11/29/89).



START 100 000.000Hz STOP 200 000 000.000Hz

REF LEVEL /DIV
0.000dB 10.000dB

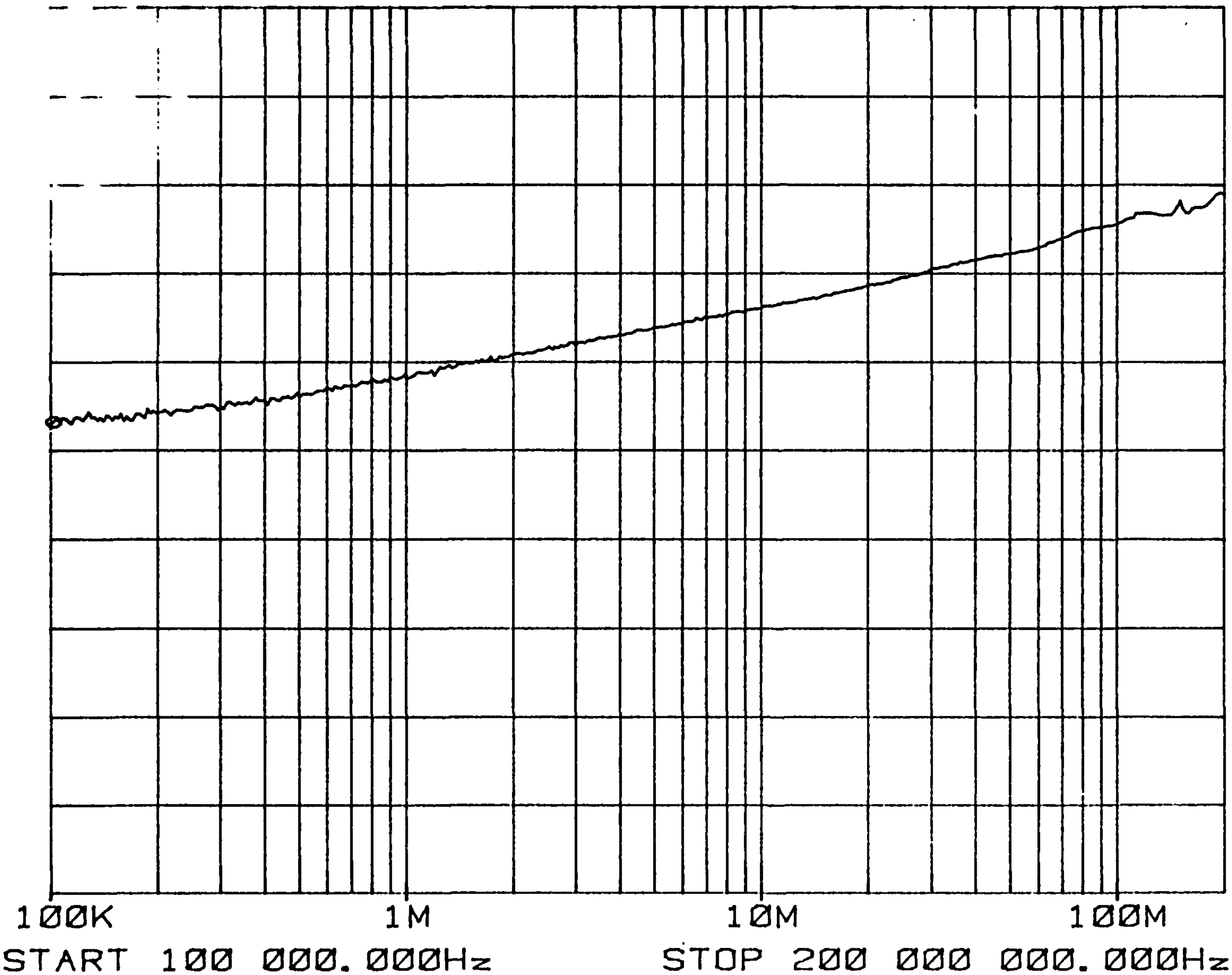
Aft side, 3" from top, initial treated (11/29/89).



START 100 000.000Hz STOP 200 000 000.000Hz

REF LEVEL /DIV MARKER 102 092.768Hz
.000dB 10.000dB MAG(UDF) -46.692dB

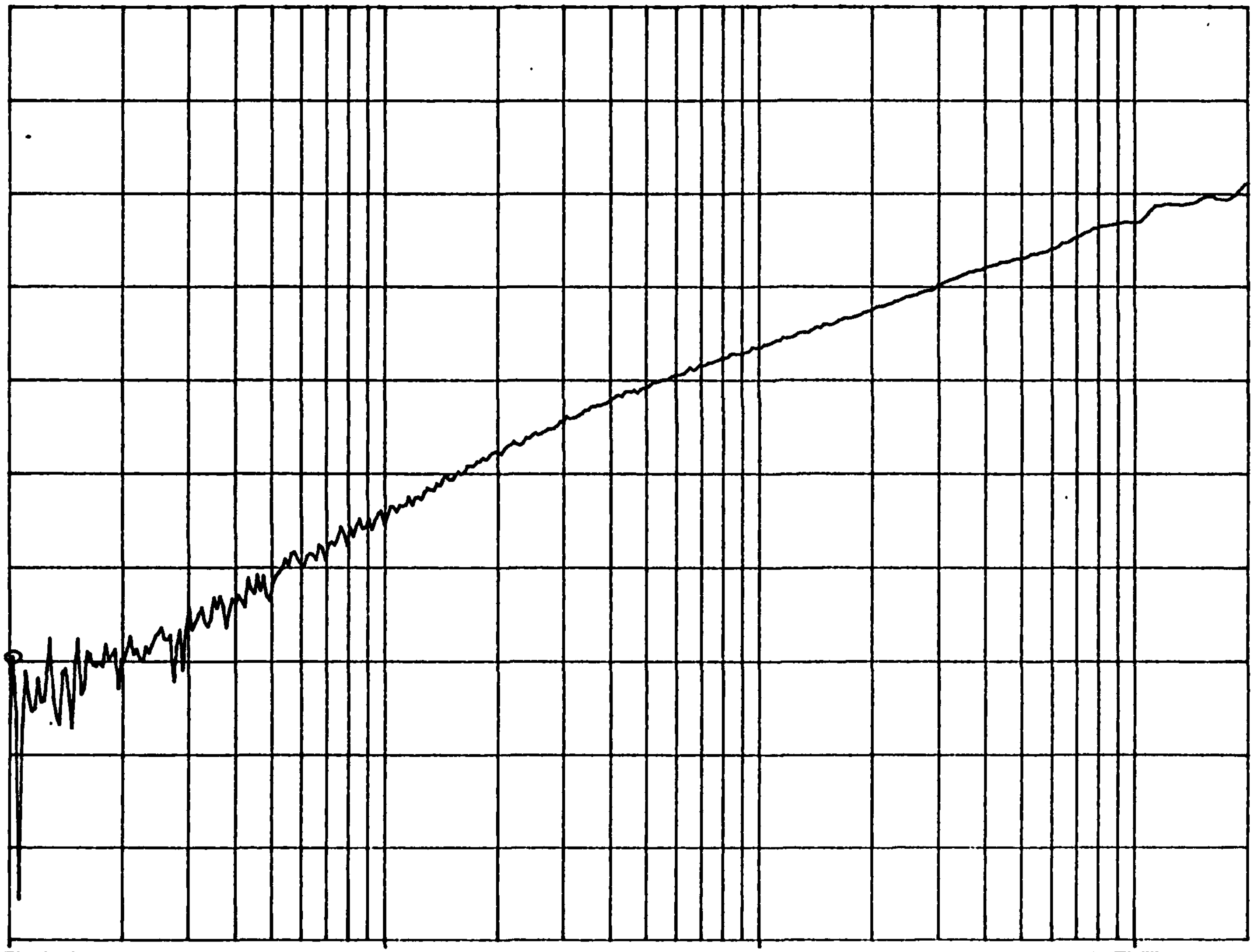
Aft side, 3" from top, retested (11/12/91).



Rdc = 1.9 mOhm
Pos. A

REF LEVEL /DIV MARKER 102 092.768Hz
0.000dB 10.000dB MAG(UDF) -69.447dB

Aft side, centered, retested(11/12/91).



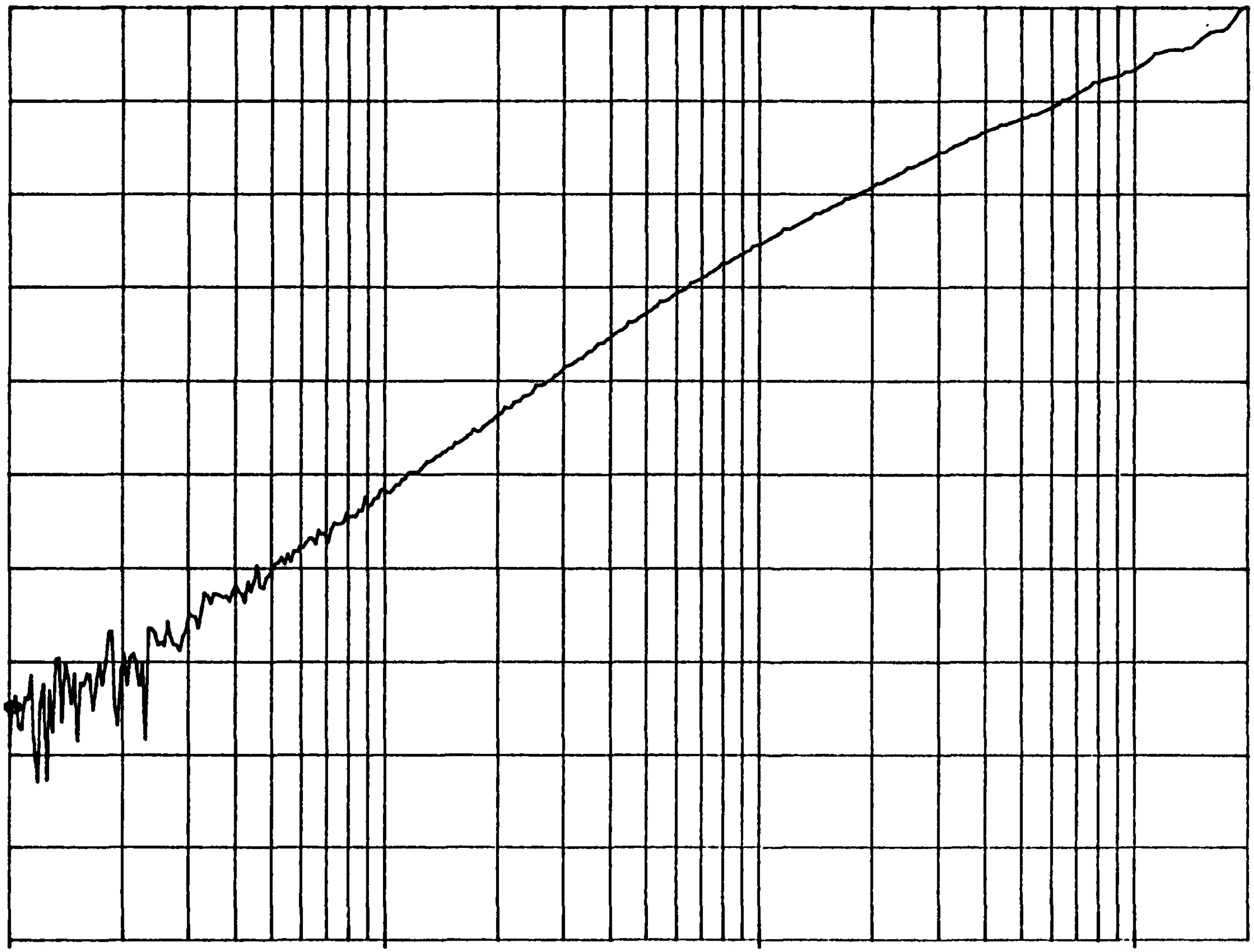
START 100 000.000Hz STOP 200 000 000.000Hz

Rdc = 0.2 mOhm

Pos. B

REF LEVEL /DIV MARKER 102 092.768Hz
0.000dB 10.000dB MAG (UDF) -74.762dB

Aft side, 3" from bottom, retested (11/12/91).



START 100 000.000Hz STOP 200 000 000.000Hz

Rdc = 0.2 mOhm

Pos. C

APPENDIX E

SPECIFICATION FOR CONDUCTIVE SEALANTS

Aerospace Materials Specification

SEALANT, ELECTRICALLY CONDUCTIVE AND CORROSION-INHIBITING

1.0 SCOPE

1.1 General

This specification covers the requirements for liquid applied electrically conductive two-part sealants for bonding bare aluminum or chemical conversion coated aluminum surfaces. The conductive sealant is effective over a continuous operation temperature of -55°C (-67°F to 248 °F).

1.2 Classification

The two-part sealant shall be particle (electrically conductive) filled elastomers including, but not limited to, polysulfide and polyurethane.

2.0 APPLICABLE DOCUMENTS

2.1 Government Documents

U.S. Government publications are available from: Commanding Office, Naval Publications and Forms Center, 5801 Table Avenue, Philadelphia, PA 19120.

2.1.1 Military Specifications, Standards and Handbooks: The following documents listed with the Department of Defense and other agencies shall apply.

MIL-STD-285	Attenuation Measurements for Enclosures, Electromagnetic Shielding, for Electronic Test Purposes, Method of
MIL-STD-794	Parts and Equipment, Procedures Packaging and Packing of
MIL-C-5541	Chemical Conversion Coating on Aluminum Alloy
MIL-S-8802	Sealing Compound, Temperature Resistant, Integral Fuel Cell Cavities, High Adhesion
MIL-C-38736	Compound Solvent, For Use in Integral Fuel Tanks
MIL-C-83528	Gasketing Materials, Conductive, Shielding Gasket, Electronic, Elastomer, EMI/RFI

2.1.2 Federal Documents::

QQ-A-250/12	Aluminum Alloy 7075, Plate and Sheet
QQ-A-250/13	Aluminum Alclad Alloy 7075, Place and Sheet
CCC-C-419	Cloth, Duck, Cotton, Unbleached, Plied Yarns, Army and Numbered
TT-M-261	Methyl ethyl Ketone, Technical
TT-1735	Isopropyl Alcohol
L-P-378	Film Properties
ASTM D 2196	Rheological Properties of Non-Newtonian Fluids
ASTM D 429	Rubber Property - Adhesion to Rigid Substrates, Method A - Rubber Part Assembled Between Two Parallel Metal Plates

2.2 American Standard Testing Methods:

ASTM publications are available from American Society for Testing Materials. 1916 Race street, Philadelphia, PA 19103.

ASTM B117	Salt Spray (Fog) Testing
ASTM D412	Tension Testing of Vulcanized Rubber
ASTM D991	Test Methods for Rubber Property - Volume Resistivity of Electricaly Conductive and Antistatic Products.
ASTM D1084	Viscosity of Adhesives
ASTM D2137	Rubber Property - Brittleness Point of Flexible Polymers and Coated Fabrics
ASTM D2240	Indention Hardness of Rubber and Plastics by Means of a Durometer, Test for
ASTM D3182	Rubber - Materials, Equipment and Plastics by Means of a Durometer, Test for

2.3 SAE Publications

SAE publications are available from: SAE, 400 Commonwealth Drive, Warrendale, PA 15096

2.3.1 Aerospace Material Specifications:

AMS 235ι - Standard Test Methods

AMS 2825 - Material Safety Data Sheets

2.4 Other Documents:

Final Reports of Georgia Tech Research Institute, No. a-4324, and Contract No. F02060-85-66007, WR-ALC, Robins Air Force Base, 31 August 1987.

Manufacturer's publications for application of sealants and material safety data sheets, available from individual supplier of materials.

3.0 TECHNICAL REQUIREMENTS

3.1 Sealant: The sealant shall consist of two parts, a base compound and a separate curing agent which, when mixed in proper proportion will cure at room temperature to a rubbery solid.

3.1.1 Base Compound: The base compound shall be an uncatalyzed polysulfide (polythioether) or polyurethane.

3.1.2 Curing Agent: The curing agent shall be of sufficiently different color from the base compound to easily identify an incompletely mixed system.

3.1.3 Surface Conditioner: Optionally, a surface conditioner may be included as part of the material package.

3.2 Physical Properties

3.2.1 Unmixed Sealant:

3.2.1.1 Storage Life: The base compound and the curing agent, stored in closed containers at no higher than 25°C, when mixed in proper proportions at any time up to three months from the date of manufacture, shall meet all requirements of this specification.

3.2.2 Mixed, Uncured Sealant:

3.2.2.1 Application Time: One-half hour after mixing, application time shall be 15 grams/minute minimum in accordance with paragraph 4.2.1. The sealant can be either extruded from a tube or troweled from a container.

3.2.2.2 Viscosity: The vendor shall supply a plot of viscosity versus time at 23 °C 5.0 minutes after mixing the two components to form the sealant mixture. This viscosity measurement shall be performed with a Brookfield Viscometer or equivalent using a No. 1 spindle below 50 RPM. Any of the various models of Brookfield Viscometers will suffice for this measurement. This

curve will represent the usable period of time before the sealant is too viscous to be workable. The period of workability after mixing shall be 1.0 hour minimum at 23°C. (73.4°F). The viscosity 1.0 hour after mixing shall not exceed 60,000 centipoise.

3.2.3 Mixed Cured Sealant: The product shall conform to the following requirements:: Tests shall be performed on specimens cut from air-free slabs prepared as in paragraph 4.4.6 and tested in accordance with specified test methods at 25 °C +/- 1°C and 45-55% relative humidity.

		Requirement	Method
3.2.3.1	Tensile strength, dry	50 psi	ASTM D 412 Method A, Die C
3.2.3.2	Elongation, Min.	50	ASTM D 412 Method A, Die C
3.2.3.3	Adhesion	40 psi	ASTM D 429 Method A
3.2.3.3	Tack Free Time, hrs.	10	para. 4.5.5
3.2.3.5	Hardness, Durometer A Minimum	40	ASTM D 2240
3.2.3.6	Thermal Properties:		
	Melting Temperature	None	para. 4.5.6.1
	Decomposition Temperature, (50% weight loss)	250°C (482.0)	para. 4.5.6.2
	Brittleness Temperature	-55°C (-67°F)	para. 4.5.6.3
3.2.3.7	D.C. Resistance, max. after an hour cure and after 2000 hrs. in salt	2.5 milliohm	para. 4.5.1
3.2.3.8	Volume Resistivity, ohm-cm spray per ASTM B 117	0.07	ASTM D 991 Para. 4.5.7
3.2.3.9	Salt Spray Chamber, 2000 hrs.	no blisters	ASTM B 117
3.2.3.10	Percent Nonvolatile, min. (potential shrinkage	95	para. 4.5.4

4.0 QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for Inspection

The vendor shall have the responsibility for initially testing the lots of base compound and curing agent before shipping, and the purchasers shall have the option to re-test when appropriate.

4.2 Classification for Tests

4.2.1 Acceptance Tests. Tests to determine conformance to the following requirements are classified as acceptance tests and shall be performed on each lot:

Requirement	Reference
Hardness	3.2.3.5
Application Time	3.2.2.1
Tack Free Time	3.2.3.4
Viscosity	4.5.3
D.C. Resistance, 24 Hours	3.2.7

4.2.2 Preproduction Tests: Tests to determine conformance to all technical requirements of this specification are classified as preproduction tests and shall be performed prior to or on the initial shipment of material to a purchaser; when a change in material, processing, or both require reapproval; and when purchaser deems confirmatory testing to be required.

4.2.2.1 For direct U.S. Military procurement, substantiating test data and, when requested, preproduction test material shall be submitted to the cognizant agency as directed by theh procuring activity, the contracting officer, or the request for procurement.

4.3 Sampling

4.3.1 For Acceptance Tests: Sufficient material shall be taken at ramdom from each lot to perform all required tests. The number of determinations for each requirement shall be as specified in the applicable test procedure.

4.3.1.1 A lot shall be all material from the same batch of raw materials processed in one continuous run and presented for vendor's smaller quantities under the basic lot approval provided lot identification is maintained.

4.3.2 For Preproduction Tests: As agreed upon by purchaser and vendor.

4.4 Approval:

4.4.1 Sample Sealant: Sample sealant material shall be approved by purchaser after material for production use has been manufactured, so that the material being tested is the same material to be supplied to the purchaser.

4.4.2 Changes: Vendor shall use ingredients, manufacturing procedures, processes, and methods of inspection on production materials which are identical to those used in the approved sample material. If any changes are proposed in the ingredients, type of equipment for processing, manufacturikng procedures, or inspection methods, the vendor shall submit for reapproval a statement of the proposed changes. If requested by the purchaser, samples of the materials shall be submitted for approval. No material shall be shipped without written approval by the purchaser.

4.5 Test Methods

4.5.1 D.C. Resistance Measurements and Test Joint Design. The objective of this test is to measure the resistance under conditions similar to actual field installations. A chemical convection coated, aluminum (70075-T6, MIL-C-5541 Class 3) test joint shall be constructed for the purpose of assuring that the performance of the sealant compiy with the requirements of this specification. The total area of the faying surfaces of the test joint shall not exceed 18 square inches. A suitable test joint is shown in Figure 1.

The test joint shall allow the sealant to be applied to one or both faying surfaces. The d.c. resistance of the sealant material shall be measured after fastening the aluminum plates together with threaded fasteners torques at standard force (13 inch-pounds). The fasteners shall be electrically insulated such that conductivity is achieved solely through the sealant material. All seams shall be directly exposed and visible to the naked eye. Resistance shall be measured with a milliohm meter (Kelvin Bridge type) capable of measuring resistance values less than 2.5 milliohms with a minimum accuracy and resolution of +/- 0.1 milliohm. The instrument probes shall be contacted directly to the base aluminum plates.

4.5.2 Adhesion of Aluminum Substrates:

Adhesion shall be measured in accordance with ASTM D 429, Rubber Property - Adhesion to Rigid Substrates, Method A - Rubber Part Assembled Between Two Parallel Metal Plates. This method is used to determine adhesion of rubber between two metal plates. The metal plate shall be chemical conversion coated (MIL-C-5541, Class 3) aluminum alloy (7075-T6).

4.5.3 Viscosity. Viscosity measurements shall be performed with a Brookfield RVF Viscometer (ASTM D 1084, Method B), at 23°C +/- 0.5°C. The spindle number and RPM shall be chosen sho that very high viscosities can be measured (refer to ASTM-D-

2196, Rheological Properties ot Non-Newtonion Fluids). The viscosity measurements shall be taken at 5.0 minute intervals, and a plot of Viscosity versus Time shall be generated to show the workable time of the sealant mixture at 25°C before gelation or unworkability.

4.5.4 <u>Percent Nonvolatile Content</u>. A 3-5 gram sample of compound shall be transferred to a cup approximately 70 mm in diameter and 3 mm deep. The sample shall be distributed evenly over the bottom surface of the cup. A fitted cup shall be placed immediately over the cup and weighed to the nearest milligram. The weight of the cover and cup shall have been determined after drying in an oven at 105°C for at least one hour. The sample shall have been cured in the cup for the 3.0 hours at 20°C to 30°C prior in the cup. The cup and sample minus the cover shall be heated in an oven at 70°C for 24 hours to expel volatiles, and weighed again to determine the weight loss due to volatile. The % nonvolatile content shall be calculated as follows:

$$\text{Nonvolatile Content, \%} = \frac{\text{Final Weight}}{\text{Initial weight}} \times 100$$

4.5.5 <u>Tack Free Time</u>: An aluminum (7975-T6) test panel conforming to QQ-A-250 shall be cleaned and covered with freshly mixed sealing compound to a depth of 0.125 inches +/- 0.002 in. The sealing material shall be allowed to cure at 25°C (77°F) at 50% relative humidity. After 10 hours, two 1 inch by 6 inch pieces of clean polyethylene film conforming to L-P-378, 0.0004 +/- .0002 inches sample shall be applied to the sealing material and held in place with a pressure of one-half ounce per square inch for 2 minutes. The strips shall be slowly and evenly withdrawn at right angles to the sealant surface. The polyethylene shall come away clean and free of sealant material.

4.5.6 <u>Thermal Stability</u>.

4.5.6.1 <u>Melting Temperature</u>: The melting temperature shall be measured using a differential scanning calorimeter (DSC). Sealant is fully cured or crosslinked. No endothermic melting peaks shall be generated on a DSC thermogram.

4.5.6.2 <u>Decomposition Temperature</u>: The temperature of thermal decomposition shall be measured using a thermogravimetric analyzer (TGA). The TGA thermogram generated from this technique shall show weight loss versus temperature in an atmosphere of nitrogen. The temperature of decomposition shall be that at which the weight loss is 50% or greater at a scan speed of 10°C/minute.

4.5.6.3 <u>Brittleness Temperature</u>: The temperature at physical brittleness or glass transition temperature shall be measured

with a differential scaning caorimeter (DSC). A transition in the generated DSC thermogram shall indicate the glass transition temperature.

4.5.7 Volume Resistivity: The dc volume resistivity of the material shall be measured in accordance with ASTM D991. The dc volume resistivity shall be calculated per ASTM D991 as follows:

$$\rho = \frac{RA}{L}$$

where: ρ = DC volume resistivity in ohm-cm,
R = measured resistance in ohms,
A = smallest cross-sectional area of sample between probe electrodes in cm^2, and
L = distance between probe electrodes in cm.

4.6 Preparation of Cured Test Sppecimens: Test specimens of the mixed, cured compound shall be cut from slabs nominally 6 in. x 6 in. and 0.075 in. +/- 0.008 in. thick, prepared from a mixture of base compound and curing agent and cured for not less than 72 hrs. at 25°C +/- 1°C and 45-55% relative humidity.

5.0 PREPARATION FOR DELIVERY

5.1 Identification

Each container shall be identified with not less than specification number, vendor's name and compound lot, date of expiration, method of storage and net quantity.

5.2 Commercial Packaging

5.2.1 Base Compound: Base compound shall be supplied in 1 pound (454 grams), 10 pounds (25 kilograms) or 450 pounds (200 kilograms) containers, as ordered. Other types of packing must be approved by the purchaser in writing.

5.2.2 Curing Agent or Catalyst: Catalyst shall be supplied in containers corresponding to the weight of the base compound (5.2.1).

5.3 Shipping

5.3.1 Shipping Sealant Components: The materials in 5.2.1 and 5.2.2 shall be prepared for shipping in accordance with commercial practice and in compliance with applicable rules and regulations pertaining to the handling, packaging and transportation of the materials to ensure carrier acceptance and safe delivery. Packaging shall conform to carrier rules and regulations applicable to the mode of transportation.

5.3.2 Shipping for Military Procurement: For direct U.S. Military procurement, packaging shall be in accordance with MIL-STD-794, Level A or Level C, as specified in the request for procurement. Commercial packaging as in 5.2 shall be acceptable if it meets the requirements of MIL-STD-794, Level C.

5.3 Storage Before/After Shipping

A suitable facility for storing the materials shall be provided including a dry enclosed area out of direct sunlight. The storage space shall be environmentally controlled. The temperature of storage shall be 20°C to 25°C and the relative humidity 50%RH to 70%RH.

6.0 DOCUMENTATION

6.1 Documentation of Lot Testing

6.1.1 Lot Testing: The vendor shall supply to the purchaser documentation forms (refer to 6.4) containing all lot testing results. With each shipment, the vendor shall furnish a report verifying conformance to the acceptance test requirements and stating that the compound conforms to the other technical requirements and this specification. This report shall include the purchase order, specification number, formula number, lot number, quantity, and all applicable test results.

6.1.2 Material Safety Data Sheets: A material safety data sheet conforming to AMS 2825 or equivalent shall be supplied to each purchaser prior to, or concurrent with, the report of preproduction test resutls. Each request for modification of compound or catalyst formulation shall be accompanied by a revised data sheet for the proposed formulation.

6.1.3 Parts: The vendor of finished or semi-finished parts shall furnish with each shipment a report showing the purchase order number, specification number, contractor or other direct supplier of sealant, supplier's sealant number, part number, and quantity. When the sealant for making parts is produced or purchased by the parts vendor, that vendor shall inspect each lot of sealant materials to determine conformance to the requirements of this specification, and will include in the report either a statement that the sealant materials conform or copies of laboratory test results showing conformance to the specification.

6.2 Documentation of Shipping

The vendor shall supply to the purchaser documentation on apaproved forms (refer to 6.4) to verify date of shipping and mode of transportation.

6.3 Documentation of Storage

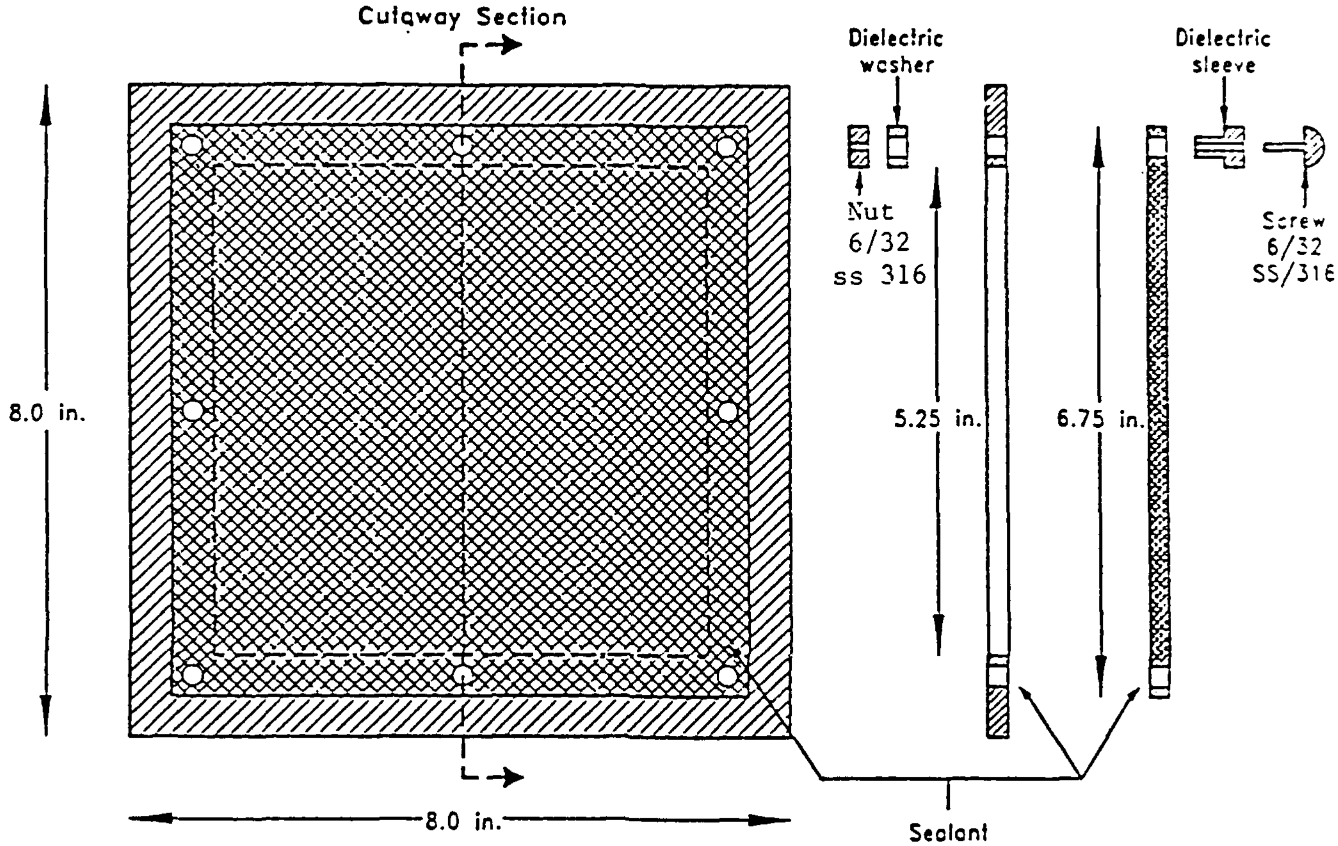
The vendor will supply documentation on inspection forms (refer to 6.4) to substantiate the duration method and facilities used for storage prior to shipping. The maximum shelf storage period prior to shipping shall not exceed three weeks.

6.4 Inspection Forms

Inspection forms shall be submitted to the purchaser so as to substantiate the quality of and test results on the materials.

6.5 Rejections

Materials not conforming to this specification or to modifications authorized by purchaser shall be subject to rejection.



Note 1: All holes are 1/4" diameter and spaced at 3" intervals

Note 2: Unless otherwise noted, all materials are 7075-T6 aluminum with MIL-C-5541 class chemical conversion coating

Figure 1. Test Joint for DC Resistance Measurements

APPENDIX F

QUALIFIED PRODUCTS LIST

QUALIFIED PRODUCTS LIST

OF

PRODUCTS QUALIFED UNDER MILITARY SPECIFICATION

SEALANT, ELECTRICALLY CONDUCTIVE, CORROSION-INHIBITING

This list has been prepared for use by or for the Government in the acquisition of products covered by the subject specification and such listing of a product is not intended to, and does not connote endorsement of the product by the Department of Defense. All products listed herein have been qualified under the requirements for the product as specified in the latest effective issue of the applicable specification. This list is subject to change without notice: revision or amendment of this list will be issued as necessary. The listing of a product does not release the supplier from compliance with the specification requirements.

GOVERNMENT DESIGNATION	MANUFACTURER'S DESIGNATION	TEST OR QUALIFICATION REFERENCE	MANUFACTURER'S NAME AND ADDRESS
	4375-29-4		Chomerics, Inc. Woburn, MA
	PR1764A-2		Products Research Corporation
	PR1764 Class B		" " "

APPENDIX G

SEALANT MANUFACTURER'S PRODUCT INFORMATION

CHOMERICS

a GRACE company

FAX
404-894-6199

June 6, 1989

Dr. Jan Gooch
GTRI
Atlanta, GA

Dear Dr. Gooch,

Chomerics 2-part silver-plated-aluminum urethane sealant system offers the following typical properties.

Product Number 4375-27-4 A/B

TEST	RESULTS (7 day R.T. Cure)
Volume Resistivity	0.03 ohm-cm
Slump	0.28 inches
Lap Shear (on Aluminum)	135 psi
Peel Strength	2.3 ppi
Hardness	91 Shore A

The stabilized copper system will have similiar physical properties. The electrical properties should be better. Volume resistivity is typically6 0.01 ohm-cm.

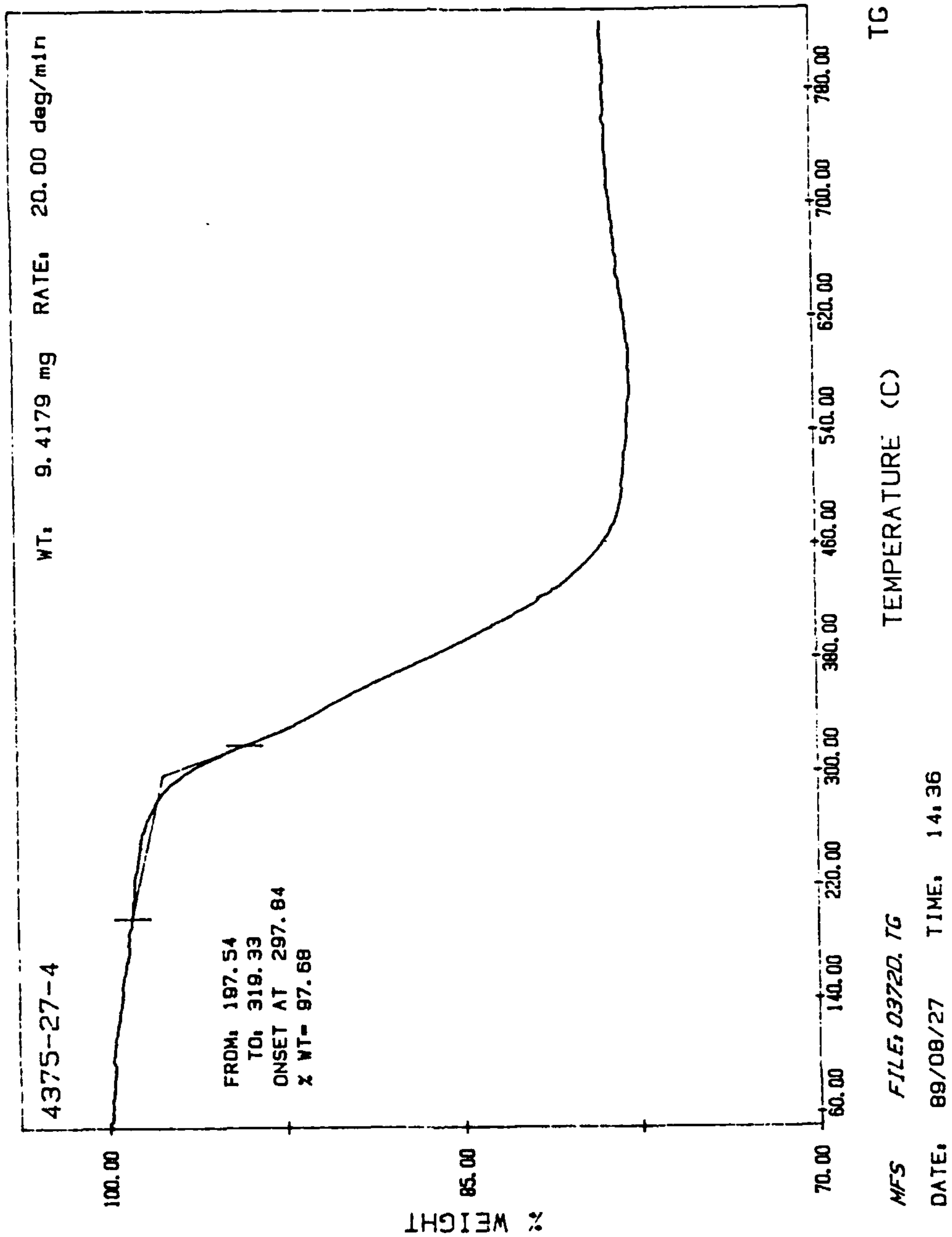
Regards,

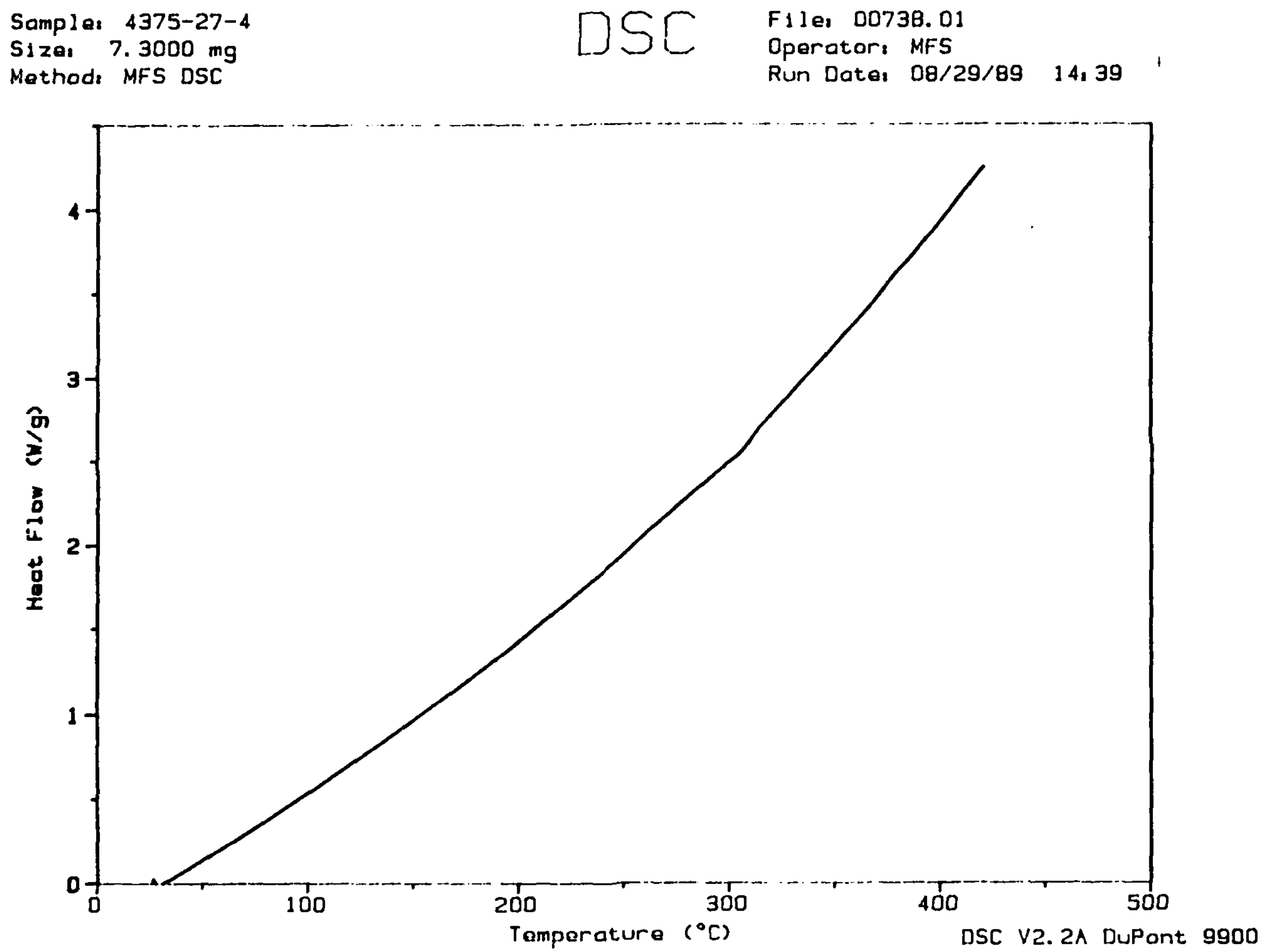
Stephen Colbert

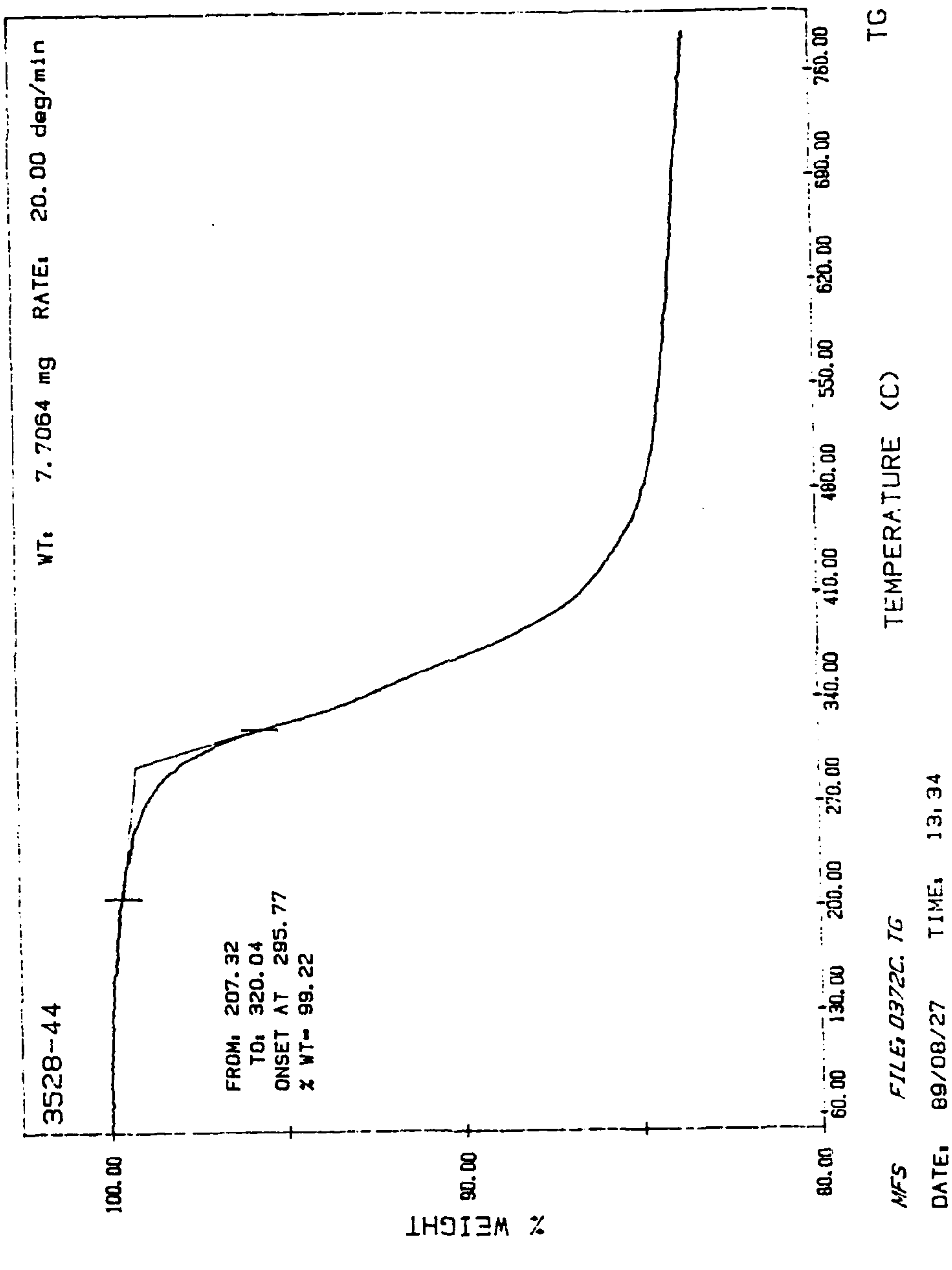
SC:pam

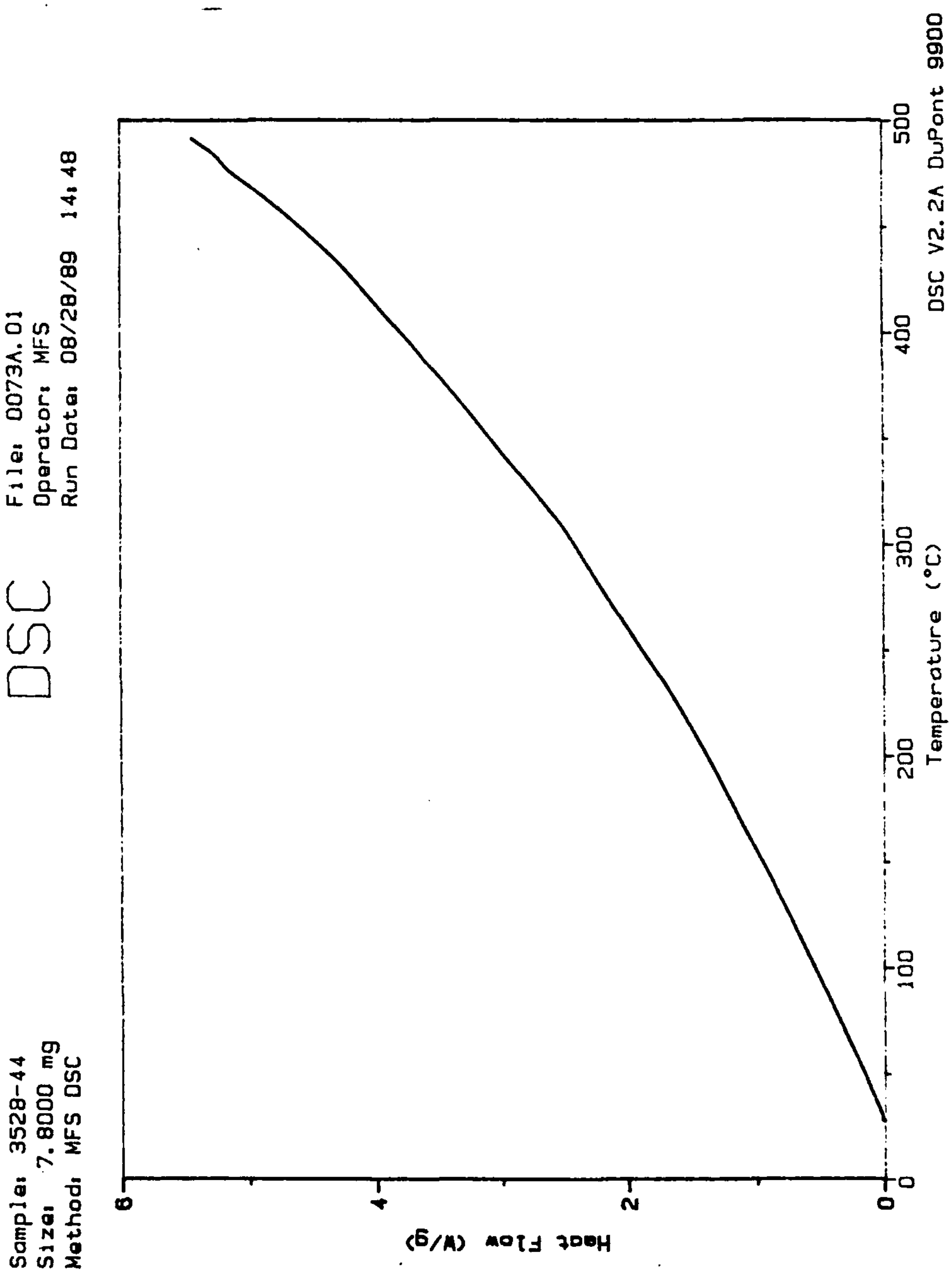
10489

[illegible]


4375-27-4
WT: 9.4179 mg RATE: 20.00 deg/min
FROM: 197.54
TO: 319.33
ONSET AT 297.84
% WT= 97.68
100.00
85.00
70.00
% WEIGHT
60.00
140.00
220.00
300.00
380.00
460.00
540.00
620.00
700.00
780.00
TEMPERATURE (C)
TG
MFS FILE: 0372D.TG
DATE: 89/08/27 TIME: 14:36


Sample: 4375-27-4
Size: 7.3000 mg
Method: MFS DSC
DSC
File: 00738.01
Operator: MFS
Run Date: 08/29/89 14:39
Heat Flow (W/g)
0
1
2
3
4
0
100
200
300
400
500
Temperature (°C)
DSC V2.2A DuPont 9900


3528-44
WT: 7.7064 mg RATE: 20.00 deg/min
FROM: 207.32
TO: 320.04
ONSET AT 295.77
% WT= 99.22
% WEIGHT
100.00
90.00
80.00
60.00
130.00
200.00
270.00
340.00
410.00
480.00
550.00
620.00
690.00
760.00
TEMPERATURE (C)
TG
MFS
FILE: 0372C. TG
DATE: 89/08/27 TIME: 13:34


Sample: 3528-44
Size: 7.8000 mg
Method: MFS DSC
DSC
File: 0073A.01
Operator: MFS
Run Date: 08/28/89 14:48
Heat Flow (W/g)
6
4
2
0
0
100
200
300
400
500
Temperature (°C)
DSC V2.2A DuPont 9900

PRC

protective coatings
caulking compounds
sealants • adhesives

LABORATORY PRODUCT REPORT

PR-1764 CLASS A

DESCRIPTION

PR-1764 Class A is a two-part, metal filled, conductive sealant, based on Permapol® P-3, a mercaptan terminated polythioether polymer covered by U.S. Patent 4,366,307.

PR-1764 Class A is resistant to jet fuel, water and oil. A soluble chromate has been added for corrosion inhibitive properties.

APPLICATION PROPERTIES (Typical)

Color	
Part A	Black
Part B	Gray
Mixed	Black
Viscosity of Part B, poise (Brookfield, spindle #6 @ 10 RPM),	100
Application Time (mixed viscosity), poise after 1 hour from time of mix	1000
Tack Free Time, hrs	10

PERFORMANCE PROPERTIES (Typical)

Specific Gravity	2.10
NVM, %	84
Cure Hardness after 24 hrs, @ CTR, rex	40
Tensile Strength, psi	
Dry	75
7 days JP-4 immersion @ 140°F	60
Elongation, %	
Dry	50
7 days JP-4 immersion @ 140°F	40

SUPERSEDES
OCT 1 5 1987

PRODUCTS RESEARCH & CHEMICAL CORPORATION
5454 SAN FERNANDO ROAD
POST OFFICE BOX 1800
GLENDALE, CALIFORNIA 91209
AREA CODE (818) 240-2060
410-418 JERSEY AVENUE
GLOUCESTER CITY, NEW JERSEY 08030
AREA CODE (609) 456-5700

DATE ISSUED
MAR 2 [illegible]

PRC

protective coatings
caulking compounds
sealants • adhesives

LABORATORY PRODUCT REPORT

PR-1764 CLASS A

DESCRIPTION

PR-1764 Class A is a two-part, metal filled, conductive sealant, based on Permapol® P-3, a mercaptan terminated polythioether polymer covered by U.S. Patent 4,366,307.

PR-1764 Class A is resistant to jet fuel, water and oil. A soluble chromate has been added for corrosion inhibitive properties.

APPLICATION PROPERTIES (Typical)

Color	
Part A	Black
Part B	Gray
Mixed	Black
Viscosity of Part B, poise (Brookfield, spindle #6 @ 10 RPM),	100
Application Time (mixed viscosity), poise after 1 hour from time of mix	1000
Tack Free Time, hrs	10

PERFORMANCE PROPERTIES (Typical)

Specific Gravity	2.10
NVM, %	84
Cure Hardness after 24 hrs, @ CTR, rex	40
Tensile Strength, psi	
Dry	75
7 days JP-4 immersion @ 140°F	60
Elongation, %	
Dry	50
7 days JP-4 immersion @ 140°F	40

Corrosion Test Salt Spray Method, 840 hrs	No evidence of corrosion and no significant change in conductivity
Insulation Resistance, ohms Applied Voltage, 100 MVDC	0.01

NOTE: Specimen of 0.04x1x3 inches in size shall be prepared from aluminum alloy conforming to temper T6 of QQ-A-250/13. Apply a 1/8 inch coat. Overlay the sealant with another panel making one square inch lap-shear test specimen.

Bulk Resistivity, ohm-cm Using micro-ohmmeter	0.07
Sheet Resistivity, ohm/square	0.48
EMI/RFI Shielding Effectiveness dB Farfield @ 1000 mH_z ASTM ES 7-83	60

Substrate primed with PR-148 Primer

NOTE: The application and performance property values are typical for the material, but are not intended for use in specifications or for acceptance inspection criteria because of variations in testing methods, conditions, and configurations.

MIXING INSTRUCTIONS

PR-1764 Class A is supplied in a two-part kit. Mix in the ratio of 10 parts A to 100 parts B by weight. Mix Part A and Part B separately to uniformity then thoroughly mix both parts together taking care to avoid leaving unmixed areas around sides or bottom of mixing container.

HEALTH PRECAUTIONS

The uncured PR-1764 Class A may produce irritation following contact with skin. When handling PR-1764 Class A, avoid ingestion and all contact with the body especially open breaks in the skin. Always wash hands before eating or smoking. Obtain medical attention in case of extreme exposure or ingestion. For additional information, see a Material Safety Data Sheet.

"PERMAPOL" is a tradename of Products Research & Chemical Corporation, registered with the U.S. Patent Office.

AFS:lod
(95)

MATERIAL SAFETY DATA SHEET

SECTION I

PRODUCT NAME:	PR-1764 Class A, C, D and Sprayable, Part A	MSDS IDENTIFICATION NO:	MS5523000
		DATE OF ISSUE:	11-17-88
		REPLACES:	None
DESCRIPTION:	Manganese Dioxide Dispersion.	PPEPARED BY:	AS
MANUFACTURER:	Products Research & Chemical Corporation 5430 San Fernando Road, P.O. Box 1800, Glendale, CA 91209		
EMERGENCY TELEPHONE:	For Emergency Medical Information (800) 228-5635 For Other Information (818) 240-2060		

SECTION II - HAZARDOUS INGREDIENTS

CHEMICAL NAME	COMMON NAME	CAS NO	% BY WT	OSHA PEL	ACGIH TLV TWA	ACGIH TLV STEL
Magnesium Chromate	Magnesium Chromate	13463-61-5	25	0.5 mg/M^3	0.05 mg/M^3	Not Est.
Manganese Dioxide *	Manganese Dioxide	1313-13-9	40	5 mg/M^3	5 mg/M^3	Not Est.

* The exposure limits are based on the measurement of airborne particles. In this product, this material is present in a fully encapsulated form and therefore airborne particles will not result from normal use.

SECTION III - PHYSICAL AND CHEMICAL CHARACTERISTICS

Boiling Point, °F.:	Not applicable.	Specific Gravity:	1.95
Vapor Pressure, mm Hg:	Not applicable.	Evaporation Rate:	Unk.
Vapor Density:	Not applicable.		
Solubility in Water:	Negligible.		

MATERIAL SA .TY DATA SHEET

SECTION I

PRODUCT NAME:	PR-1764 Class A, C, D and Sprayable, Part A	MSDS IDENTIFICATION NO:	MS5523000
		DATE OF ISSUE:	11-17-88
		REPLACES:	None
DESCRIPTION:	Manganese Dioxide Dispersion.	PREPARED BY:	AS
MANUFACTURER:	Products Research & Chemical Corporation 5430 San Fernando Road, P.O. Box 1800, Glendale, CA 91209		
EMERGENCY TELEPHONE:	For Emergency Medical Information (800) 228-5635 For Other Information (818) 240-2060		

SECTION II - HAZARDOUS INGREDIENTS

CHEMICAL NAME	COMMON NAME	CAS NO	% BY WT	OSHA PEL	ACGIH TLV TWA	ACGIH TLV STEL
Magnesium Chromate	Magnesium Chromate	13463-61-5	25	0.5 mg/M^3	0.05 mg/M^3	Not Est.
Manganese Dioxide *	Manganese Dioxide	1313-13-9	40	5 mg/M^3	5 mg/M^3	Not Est.

* The exposure limits are based on the measurement of airborne particles. In this product, this material is present in a fully encapsulated form and therefore airborne particles will not result from normal use.

SECTION III - PHYSICAL AND CHEMICAL CHARACTERISTICS

Boiling Point, °F.:	Not applicable.	Specific Gravity:	1.95
Vapor Pressure, mm Hg:	Not applicable.	Evaporation Rate:	Unk.
Vapor Density:	Not applicable.		
Solubility in Water:	Negligible.		

SECTION VI - EMERGENCY FIRST AID PROCEDURES

Eyes:	Flush with luke warm water for 15 minutes. If symptoms persist, consult physician.
Skin:	Wash with soap and water, consult a physician.
Inhalation:	Remove to fresh air. If symptoms are present consult a physician.
Ingestion:	Consult a physician.

SECTION VII - SUGGESTED CONTROL PROCEDURES

Ventilation:	General ventilation to maintain vapor below TLV.
Skin Protection:	Solvent resistant gloves.
Eye Protection:	Safety glasses.

SECTION VIII - SPILL OR LEAKAGE PROCEDURES

Release or Spillage:	Remove all ignition sources. Wear air-supplied respirator for major unventilated spill. Clean-up residue with 1,1,1 -trichloroethane.
Waste Disposal:	EPA Waste No. D-001. Dispose of spillage in compliance with Federal and State regulations.

SECTION IX - SPECIAL PRECAUTIONS

This product contains a toxic chemical or chemicals subject to the reporting requirements of Section 313 of Title III of the Superfund Amendments and Reauthorization Act of 1986 and 40 CFR Part 372.

The information provided herein is, to the best of the manufacturer's knowledge, current, accurate and complete, based on information reasonably available.

MATERIAL SAFETY DATA SHEET

SECTION I

PRODUCT NAME:	PR-1764 Class A, Part B	MSDS IDENTIFICATION NO:	MS3995B00
		DATE OF ISSUE:	10-10-88
		REPLACES:	None
DESCRIPTION:	Mercaptan Terminated Polythioether Compound.	PREPARED BY:	JCS
MANUFACTURER:	Products Research & Chemical Corporation 5430 San Fernando Road, P.O. Box 1800, Glendale, CA 91209		
EMERGENCY TELEPHONE:	For Emergency Medical Information (800) 228-5635 For Other Information (818) 240-2060		

SECTION II - HAZARDOUS INGREDIENTS

CHEMICAL NAME	COMMON NAME	CAS NO	% BY WT	OSHA PEL	ACGIH TLV TWA	ACGIH TLV STEL
Methyl Benzene	Toluene	108-88-3	15	200 ppm	100 ppm	150 ppm
Nickel Powder	Nickel Powder	7440-02-0	65	1 mg/M^3	Not Est.	Not Est.
Phenol polymer with formaldehyde	Phenolic Resin	9003-35-4	<5	Not Est.	Not Est.	Not Est.

SECTION III - PHYSICAL AND CHEMICAL CHARACTERISTICS

Boiling Point, °F.:	Unk.	Specific Gravity:	1.83
Vapor Pressure, mm Hg:	Unk.	VOC, g/l (Mixed):	274
Vapor Density:	2.42 (MEK).		
Solubility in Water:	Negligible.		

MATERIAL SAFETY DATA SHEET

SECTION I

PRODUCT NAME:	PR-1764 Class A, Part B	MSDS IDENTIFICATION NO:	MS3995800
		DATE OF ISSUE:	10-10-88
DESCRIPTION:	Mercaptan Terminated Polythioether Compound.	REPLACES:	None
		PREPARED BY:	JCS
MANUFACTURER:	Products Research & Chemical Corporation 5430 San Fernando Road, P.O. Box 1800, Glendale, CA 91209		
EMERGENCY TELEPHONE:	For Emergency Medical Information (800) 228-5635 For Other Information (818) 240-2060		

SECTION II - HAZARDOUS INGREDIENTS

CHEMICAL NAME	COMMON NAME	CAS NO	% BY WT	OSHA PEL	ACGIH TLV TWA	ACGIH TLV STEL
Methyl Benzene	Toluene	108-88-3	15	200 ppm	100 ppm	150 ppm
Nickel Powder	Nickel Powder	7440-02-0	65	1 mg/M^3	Not Est.	Not Est.
Phenol polymer with formaldehyde	Phenolic Resin	9003-35-4	<5	Not Est.	Not Est.	Not Est.

SECTION III - PHYSICAL AND CHEMICAL CHARACTERISTICS

Boiling Point, °F.:	Unk.	Specific Gravity:	1.83
Vapor Pressure, mm Hg:	Unk.	VOC, g/l (Mixed):	274
Vapor Density:	2.42 (MEK).		
Solubility in Water:	Negligible.		

SECTION VI - EMERGENCY FIRST AID PROCEDURES

Eyes:	Flush with luke warm water for 15 minutes. If symptoms persist, consult physician.
Skin:	Wash with soap and water. If symptoms persist, consult a physician.
Inhalation:	Remove to fresh air. If symptoms are present consult a physician.
Ingestion:	Consult a physician.

SECTION VII - SUGGESTED CONTROL PROCEDURES

Ventilation:	General ventilation.
Skin Protection:	Solvent resistant gloves.
Eye Protection:	Safety glasses.

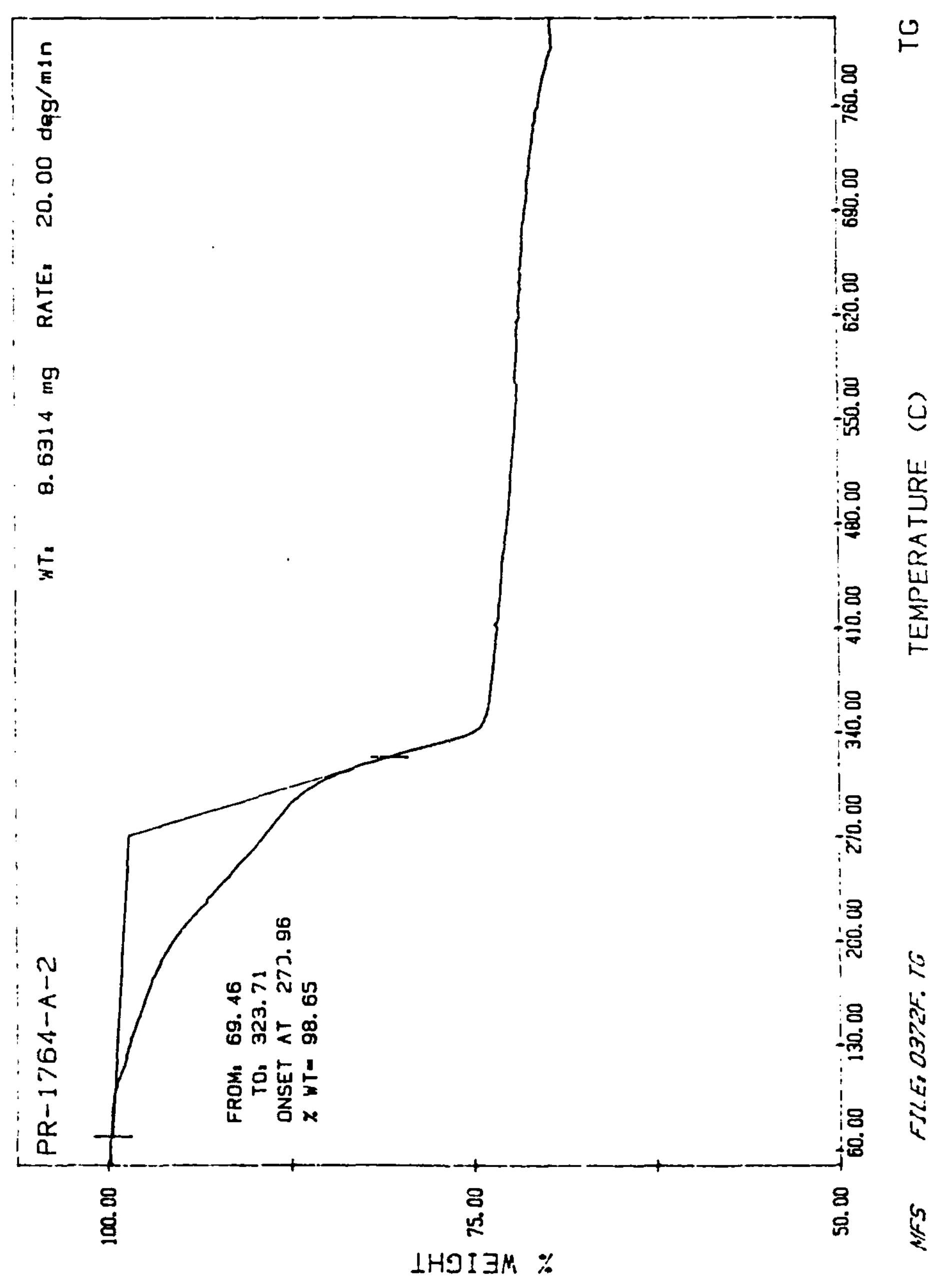
SECTION VIII - SPILL OR LEAKAGE PROCEDURES

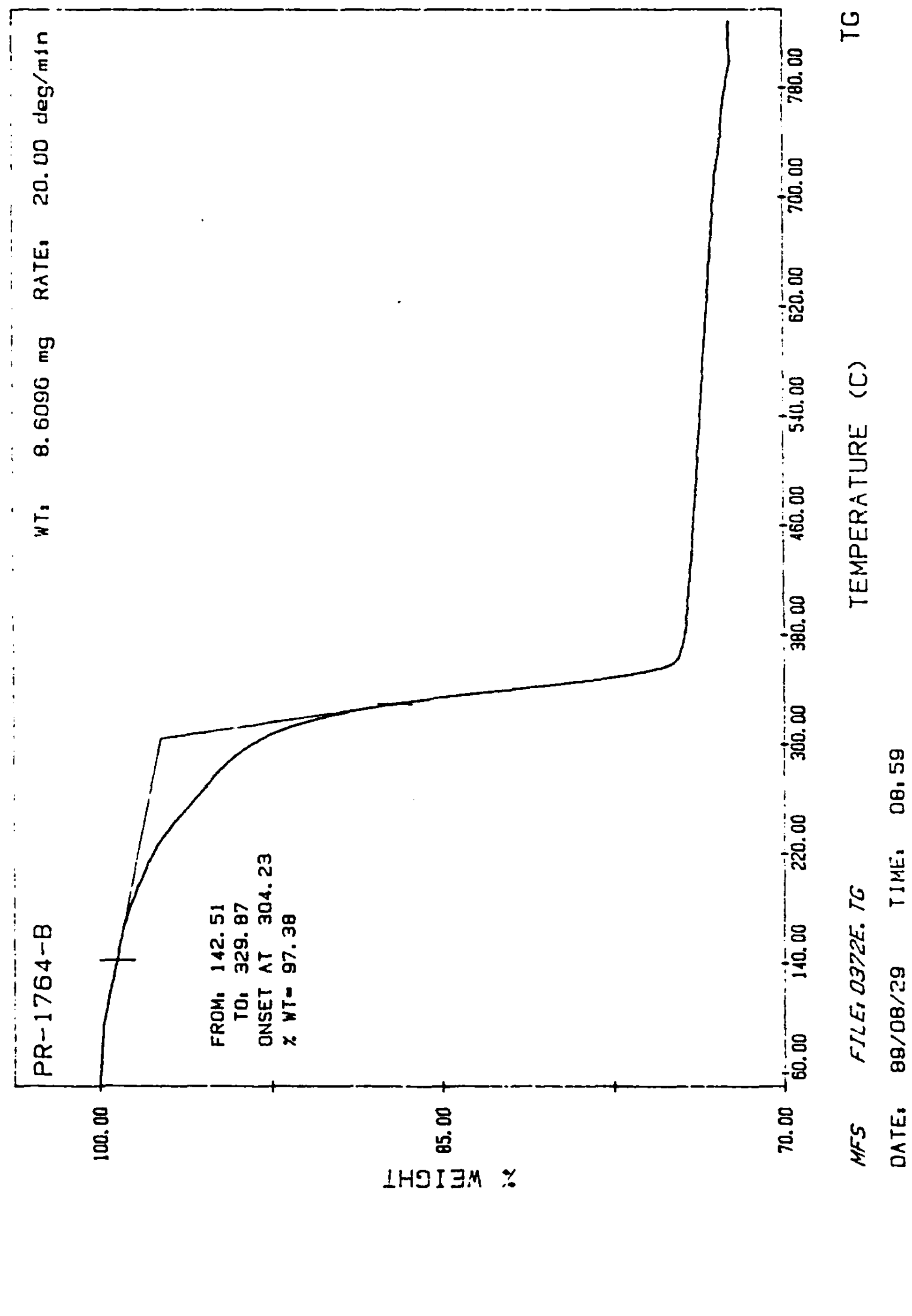
Release or Spillage:	Scoop into containers. Clean-up residue with 1,1,1 -trichloroethane.
Waste Disposal:	EPA Waste No. D-007. Dispose of spillage in compliance with Federal and State regulations.

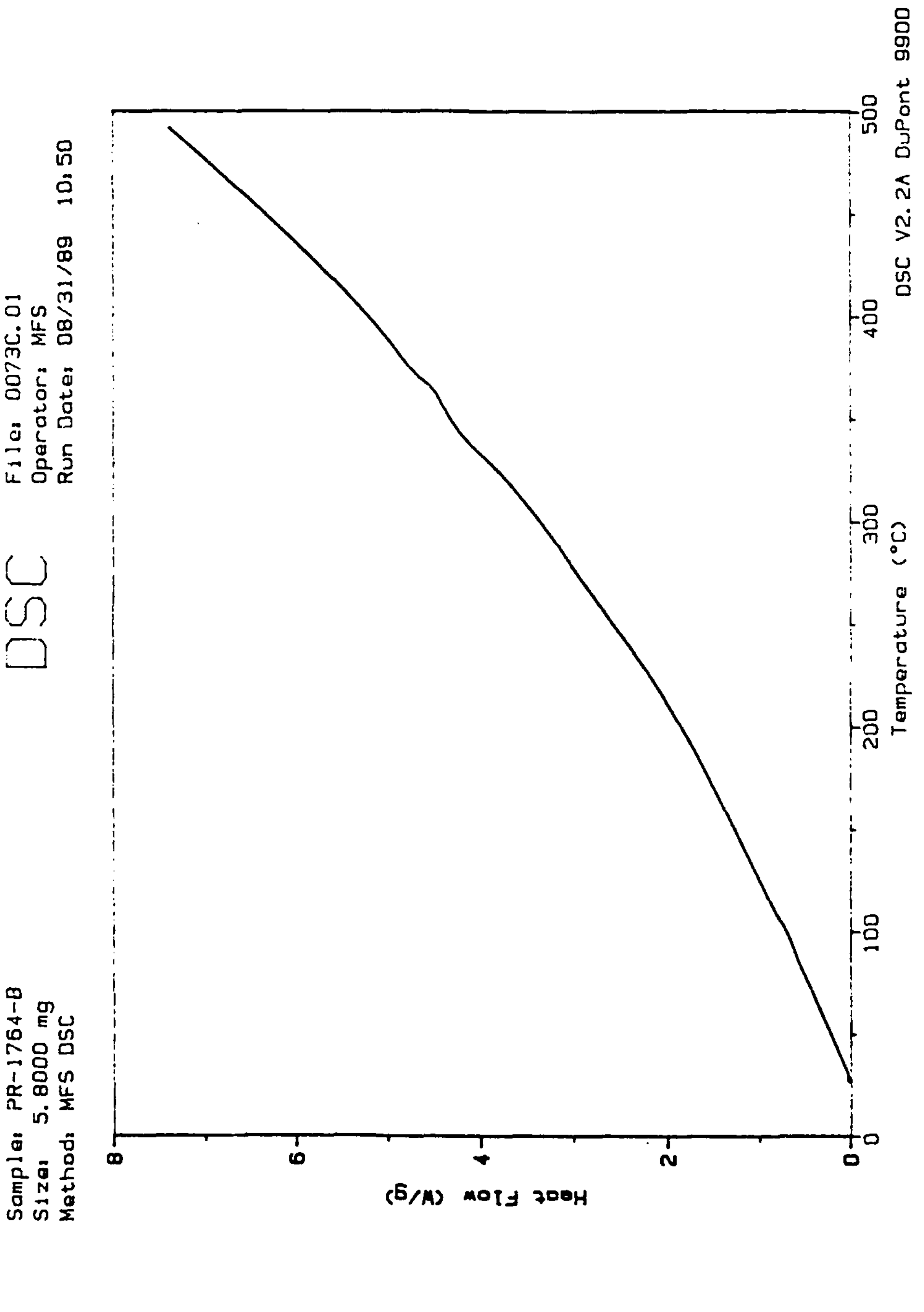
SECTION IX - SPECIAL PRECAUTIONS

Wash thoroughly after handling and before smoking or eating. Avoid ingestion. This product contains a toxic chemical or chemicals subject to the reporting requirements of Section 313 of Title III of the Superfund Amendments and Reauthorization Act of 1986 and 40 CFR Part 372.

The information provided herein is, to the best of the manufacturer's knowledge, current, accurate and complete, based on information reasonably available.


PR-1764-A-2
WT: 8.6314 mg RATE: 20.00 deg/min
FROM: 69.46
TO: 323.71
ONSET AT 27?.96
% WT= 98.65
100.00
75.00
50.00
% WEIGHT
60.00
130.00
200.00
270.00
340.00
410.00
480.00
550.00
620.00
690.00
760.00
TEMPERATURE (C)
TG
MFS FILE: 0372F. TG
DATE: 89/08/29 TIME: 03:01


PR-1764-B
WT: 8.6096 mg
RATE: 20.00 deg/min
FROM: 142.51
TO: 329.87
ONSET AT 304.23
% WT= 97.38
100.00
85.00
70.00
% WEIGHT
60.00
140.00
220.00
300.00
380.00
460.00
540.00
620.00
700.00
780.00
TEMPERATURE (C)
TG
MFS
FILE: 0372E.TG
DATE: 89/08/29
TIME: 08:59



Sample: PR-1764-B
Size: 5.8000 mg
Method: MFS DSC
DSC
File: 0073C.01
Operator: MFS
Run Date: 08/31/89 10:50
Heat Flow (W/g)
8
6
4
2
0
0
100
200
300
400
500
Temperature (°C)
DSC V2.2A DuPont 9900